NASA Conference Publication 10004
DOT/FAA/PS-87/2

Wind Shear Detection

Forward-Looking Sensor Technology

Compiled by
E. M. Bracalente
Langley Research Center
Hampton, Virginia

V. E. Delnore
PRC Kentron, Inc.
Hampton, Virginia

Collected viewgraphs and notes
from the first industry review
sponsored by the National Aeronautics
and Space Administration and the Federal
Aviation Administration and held at
NASA Langley Research Center
Hampton, Virginia
February 24–25, 1987

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October 1987

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INTRODUCTION

A meeting took place at the NASA Langley Research Center on the 24th and 25th of February 1987 to discuss the development and eventual use of forward-looking remote sensors for the detection and avoidance of wind shear by aircraft. Industry was represented by several radar manufacturers, software developers, and aircraft operators; the academic community by several research institutions with university affiliations; and government by NASA and the FAA.

As is evident from the Preliminary Agenda (page 7), the meeting was structured to first provide a review of the current FAA and NASA wind shear programs, then to define what really happens to the airplane, and finally to give technology updates on the various types of forward-looking sensors. Except for certain time adjustments, this schedule was maintained, and then followed by discussions to define the key issues which remain unresolved from this meeting.

The present document has been compiled to informally record the essence of the technology updates and the discussions which followed each. The updates are represented here through the unedited duplication of the vugraphs, which were generously provided by the respective speakers. To encourage the participants to speak freely, no audio tape recordings were made of the formal presentations; thus no transcript appears here. However, during the floor discussion following each presentation, notes were kept by several of the Langley participants. These were abstracted and appear in this volume, beginning on page 272.

In the final section of this document are listed the key issues which remain unresolved from the meeting. Hopefully, they will form the basis of the next meeting on forward-looking sensors.

LIST OF PARTICIPANTS

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Industry/FAA/NASA Mtg.

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LaRC = Langley Research Center
NCAR = National Center for Atmospheric Research
PRC = Planning Research Corporation
AMRB = Antenna & Microwave Research Branch
MIT = MIT

PRELIMINARY AGENDA

Tuesday, 24 February 1987   Building 1212, Room 200

0830	Start - Opening Remarks
0845	Review of Integrated FAA Wind Shear Program
0900	Review of the Airborne Wind Shear Detection and Avoidance Program
0930	"The Hit on the Airplane" - The Effect of Wind Shear on Aerodynamic Performance
1000	Forward Look Options:
	Microwave Radar
	Lidar
	Infrared Radiometry
	Other Options
1130	Lunch
1300	Forward Look Options (cont'd)
1600	Review of NASA Base Technology for Solid State Lasers
1630	Conclusion

Wednesday, 25 February

0830	Start
0900	Defining a Consensus
1000	Conclusion

ACTUAL AGENDA

Tuesday, 24 February, 1987

0830	Introductory Remarks	R. L. Bowles, G. C. Hay
0851	Wind Shear Modeling - DFW Case Study	R. L. Bowles
	NASA Airborne Wind Shear Detection and Avoidance Program	R. L. Bowles
	Wind Shear Detection, Warning, and Flight Guidance	R. L. Bowles
0937	Airborne Doppler Technology for Wind Shear Detection	E. M. Bracalente
1038	Radar Simulation Studies at AMRB, NASA LaRC	C. L. Britt
1130	Lunch	
1315	Radar Application Issues	P. Hildebrand
1349	Wind Shear Considerations for Forward-Looking System	R. Robertson
1430	Wind Shear Avoidance with an Airborne Laser	R. Targ
1600	Update on Solid State Lidar Base Technolgy at LaRC	F. Allario

Wednesday, 25 February 1987

0830	CO_2 Laser Technology for Wind Shear Detection	J. Ewing, S. Byron
0848	Lidar Measuring Concept	R. M. Huffaker
0948	Infra Red	P. Adamson
1118	Infra Red System for Detection of Wind Shear	W. A. Siarnicki, T. D. Wise
1210	Discussion on Key Issues for Next Meeting	All

WIND SHEAR MODELING:
DFW CASE STUDY

R. L. Bowles
NASA/LaRC

WIND SHEAR MODELING - DFW CASE STUDY

Presented To:

NASA/FAA/Industry/Universities
Sensor Technology
Review Meeting
February 24-25,1987

Dr. R.L. Bowles

ADVANCED NUMERICAL WEATHER MODELS BASED ON FLUID-FLOW THEORETIC TECHNIQUES

PROBLEM:

LACK OF HIGH-FIDELITY WIND SHEAR MODEL FOR SAFETY-RELATED STUDIES OF A/C PERFORMANCE/CREW PROCEDURES/AVIONICS SYSTEM BENEFITS

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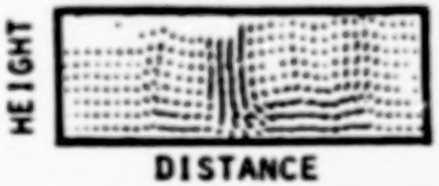
WIND VELOCITIES (JAWS)
- REAL-WORLD MEASUREMENTS
- BUT, COARSE GRID



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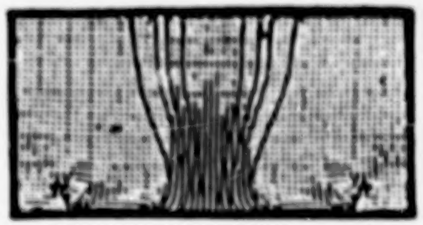
THEORY

FLUID-FLOW-BASED
- SMOOTHING
- INTERPOLATION
- PREDICTION

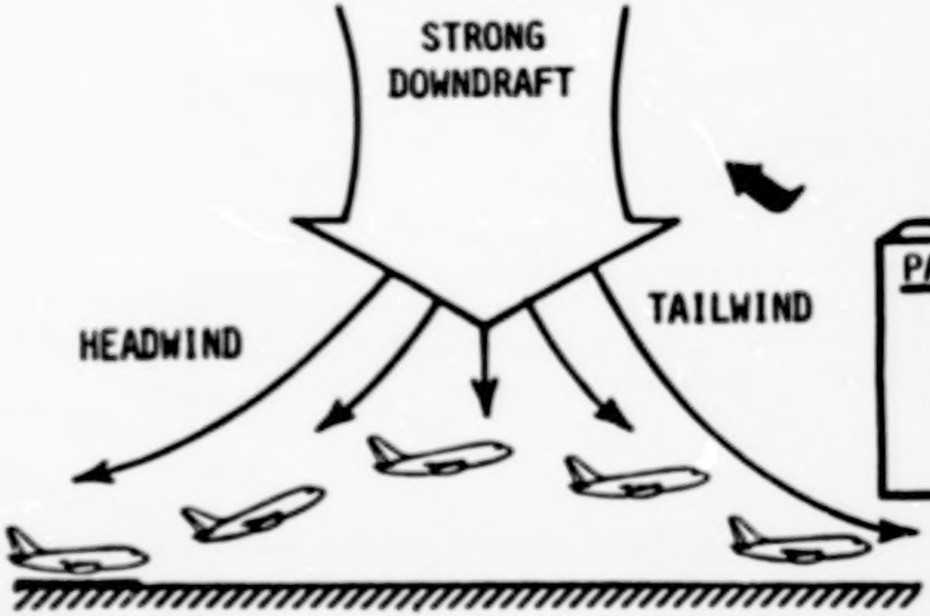
=



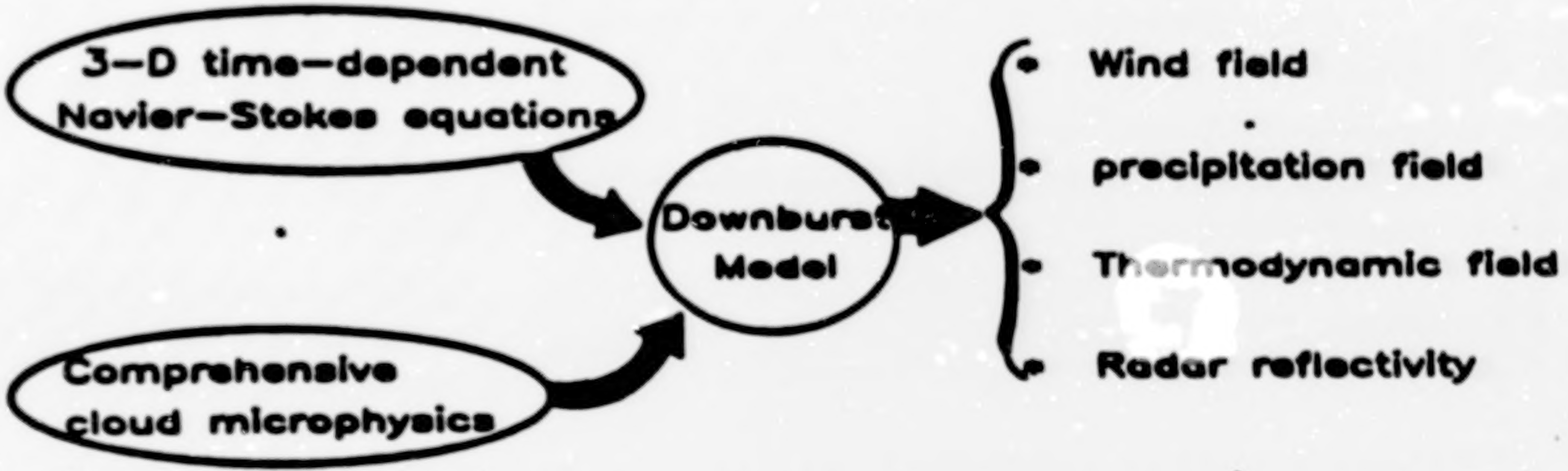
RESULT:

HIGH RESOLUTION MODELS
BASED ON ACTUAL
WIND SHEAR MEASUREMENTS

PAYOFF:
- REALISTIC REPRESENTATION OF SEVERE WEATHER
- VERIFIED CAPABILITY FOR CONDUCTING SAFETY-RELATED RESEARCH



ADVANCED WIND SHEAR MODEL



FEATURES

- 3–D time–dependent Navier–Stokes equations
- Comprehensive cloud microphysics

Downburst Model

OUTPUT

- Wind field
- precipitation field
- Thermodynamic field
- Radar reflectivity

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.
.

Considered by industry as major technical asset

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DFW DOWNBURST SIMULATION – AUGUST 2, 1986

INPUT DATA/ASSUMPTIONS

- SOUNDING DERIVED FROM MESO–SCALE INITIALIZATION PACKAGE ADJUSTED TO AGREE WITH DFW 6 PM CDT SURFACE TEMPERATURE AND DEW POINT
  - NWS – LFM ANALYSIS
  - RAWINSONDES (70 U.S. AND NORTHERN MEXICO)

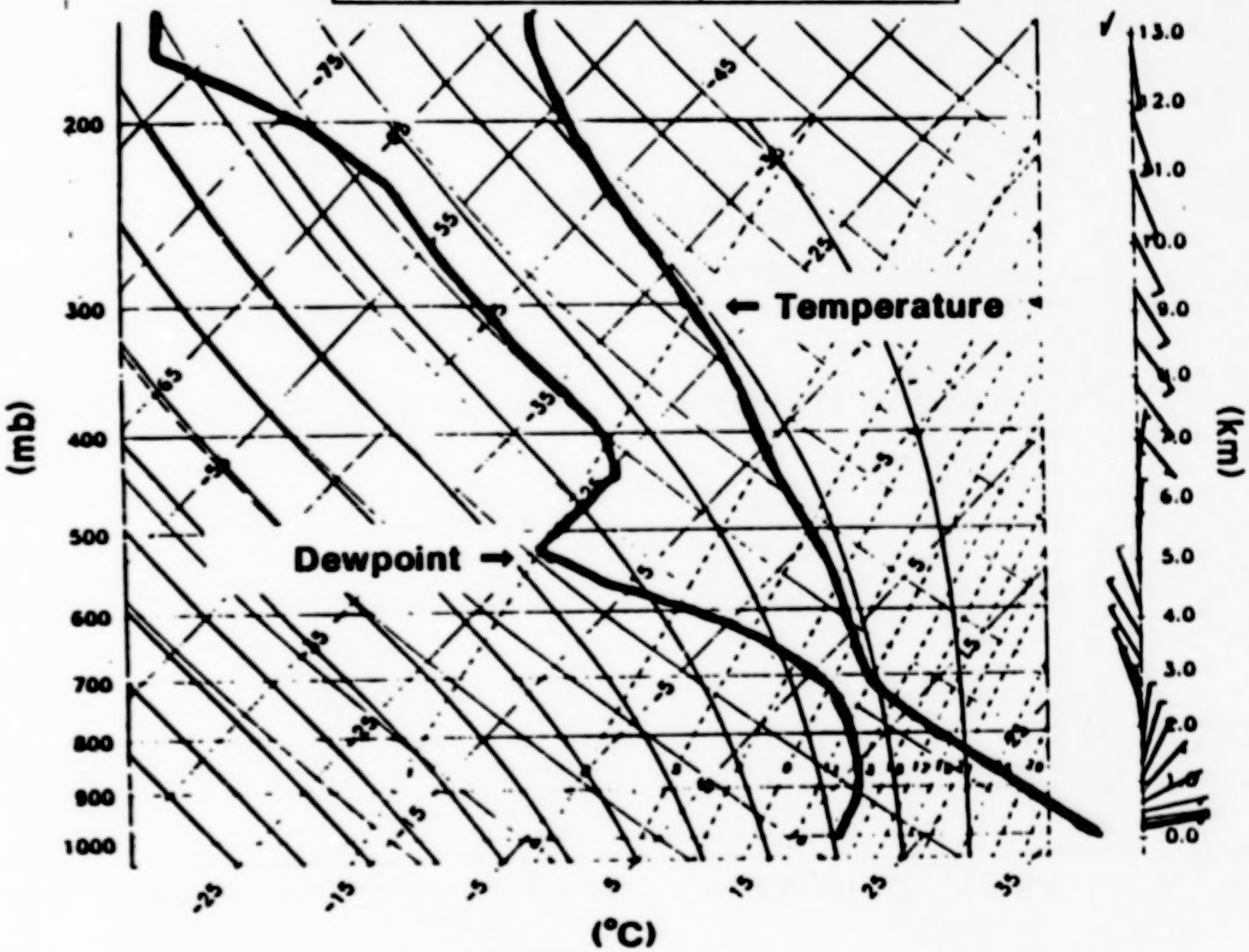
- COMPUTATIONAL RESOLUTION
  - HORIZONTAL – 200 M
  - VERTICAL – 100 M NEAR GROUND TO 1000 M AT 18 KM ALTITUDE

- PHYSICAL DOMAIN SIZE – 12 KM X 12 KM X 18 KM

- CONVECTIVE INITIATION AT TIME ZERO
  - SPHEROIDAL THERMAL IMPULSE
  - DIMENSIONS – 5 KM HORIZONTAL, 3 KM VERTICAL

DERIVED DFW SOUNDING

Aug. 2, 1985 - 6 PM CDT



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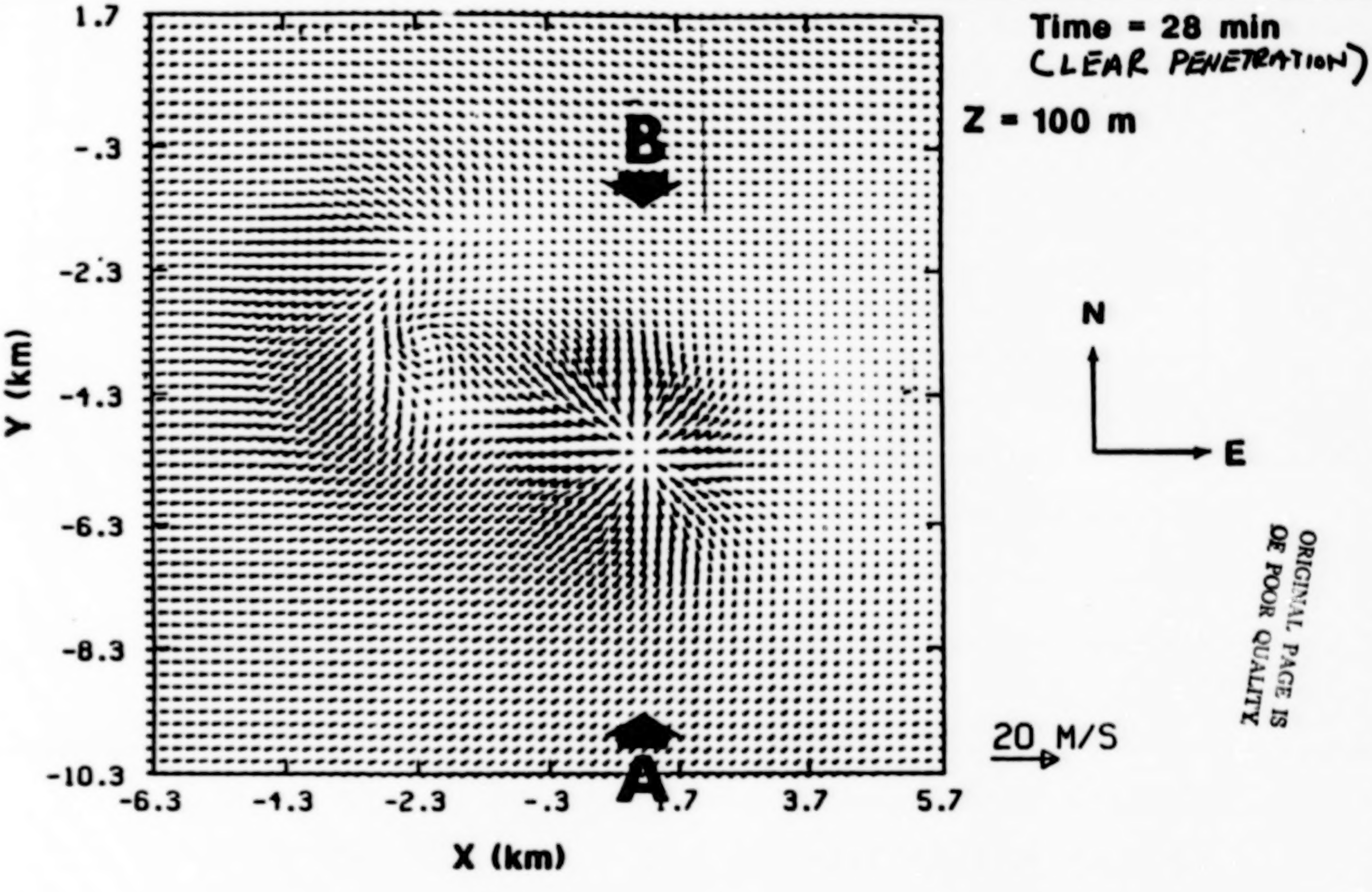
DALLAS MICROBURST SIMULATION STUDY USING LARC FLUID/CLOUD PHYSICS MODEL



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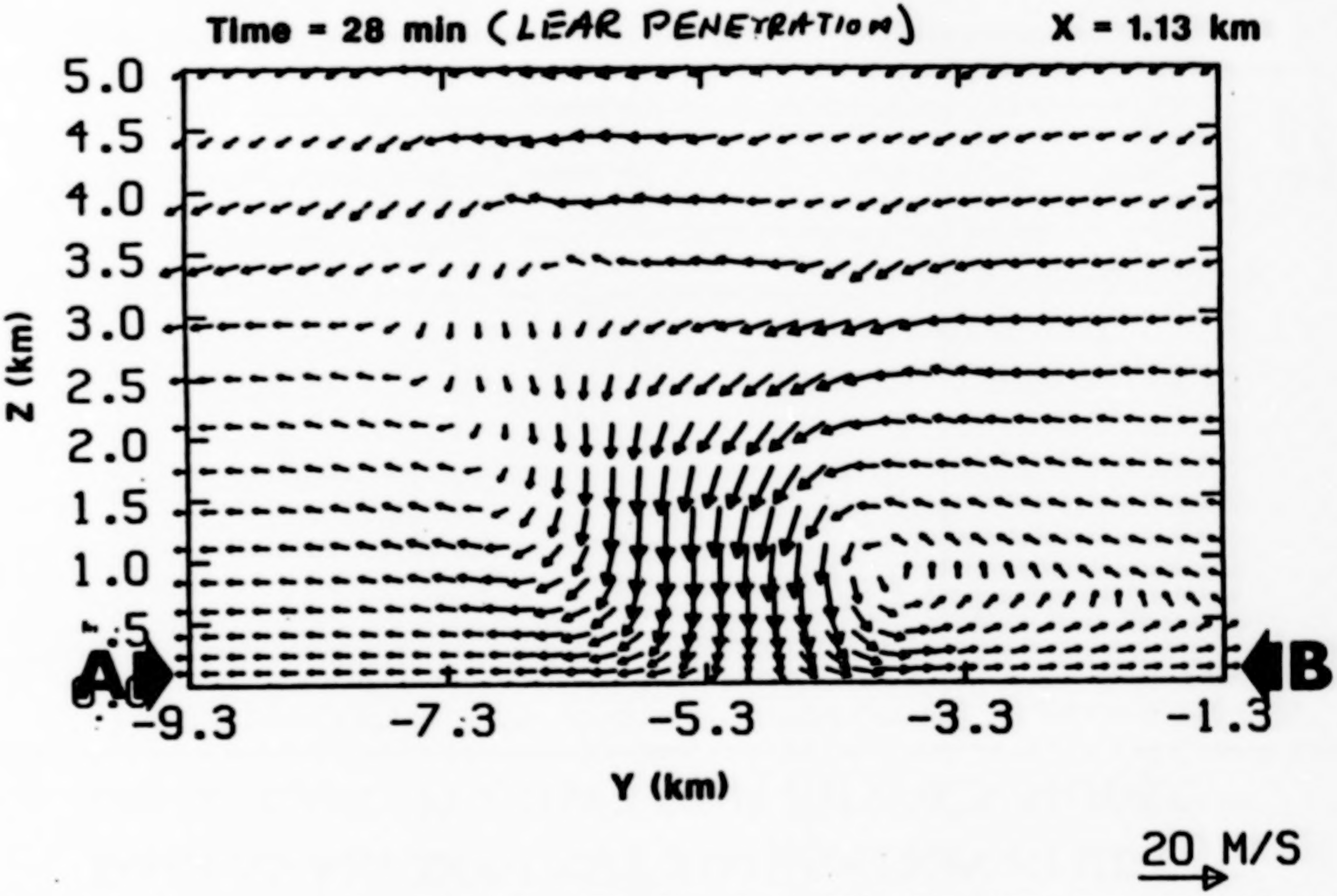
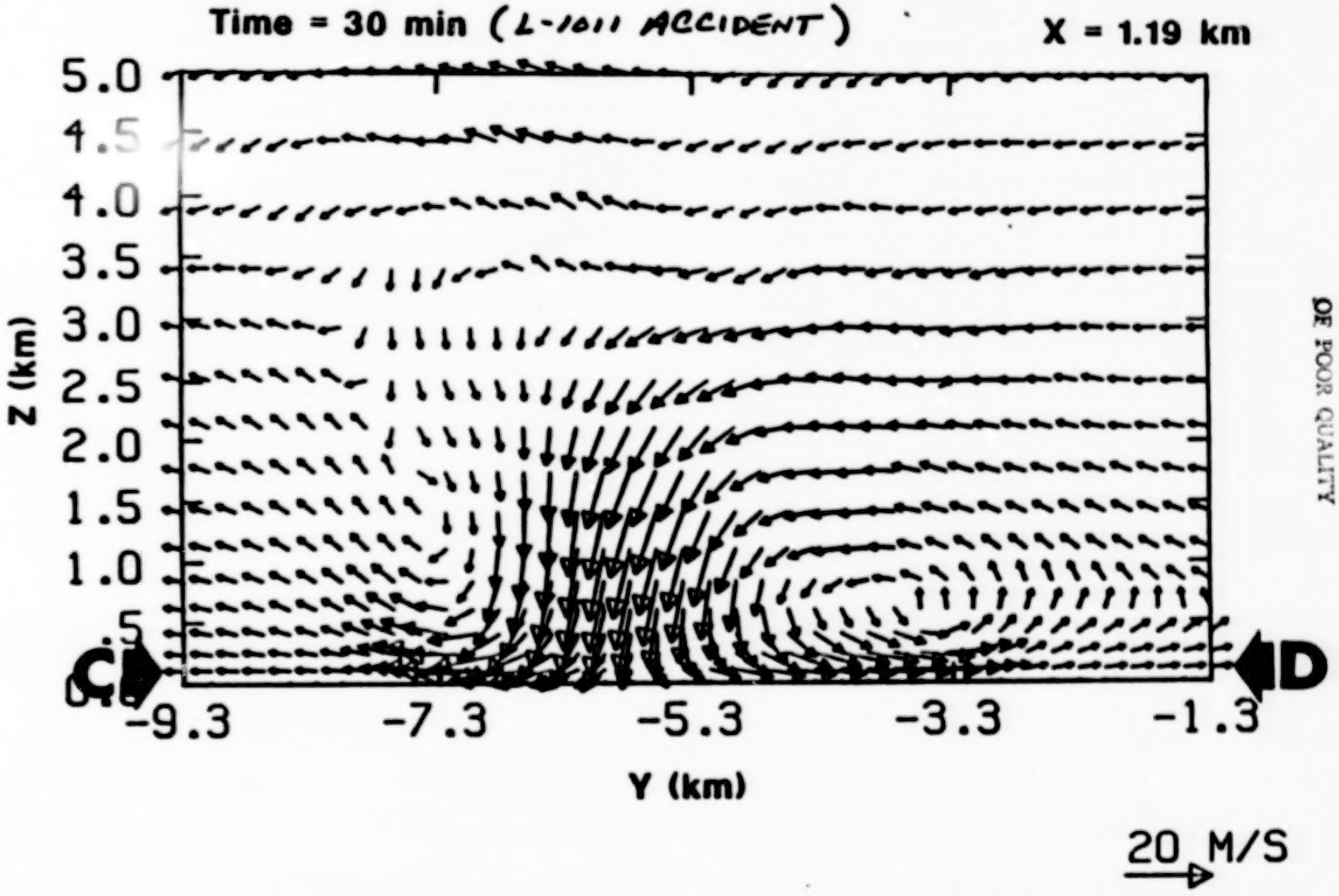


Time = 28 min (LEAR PENETRATION) X = 1.13 km

DALLAS MICROBURST SIMULATION STUDY
USING LARC FLUID/CLOUD PHYSICS MODEL



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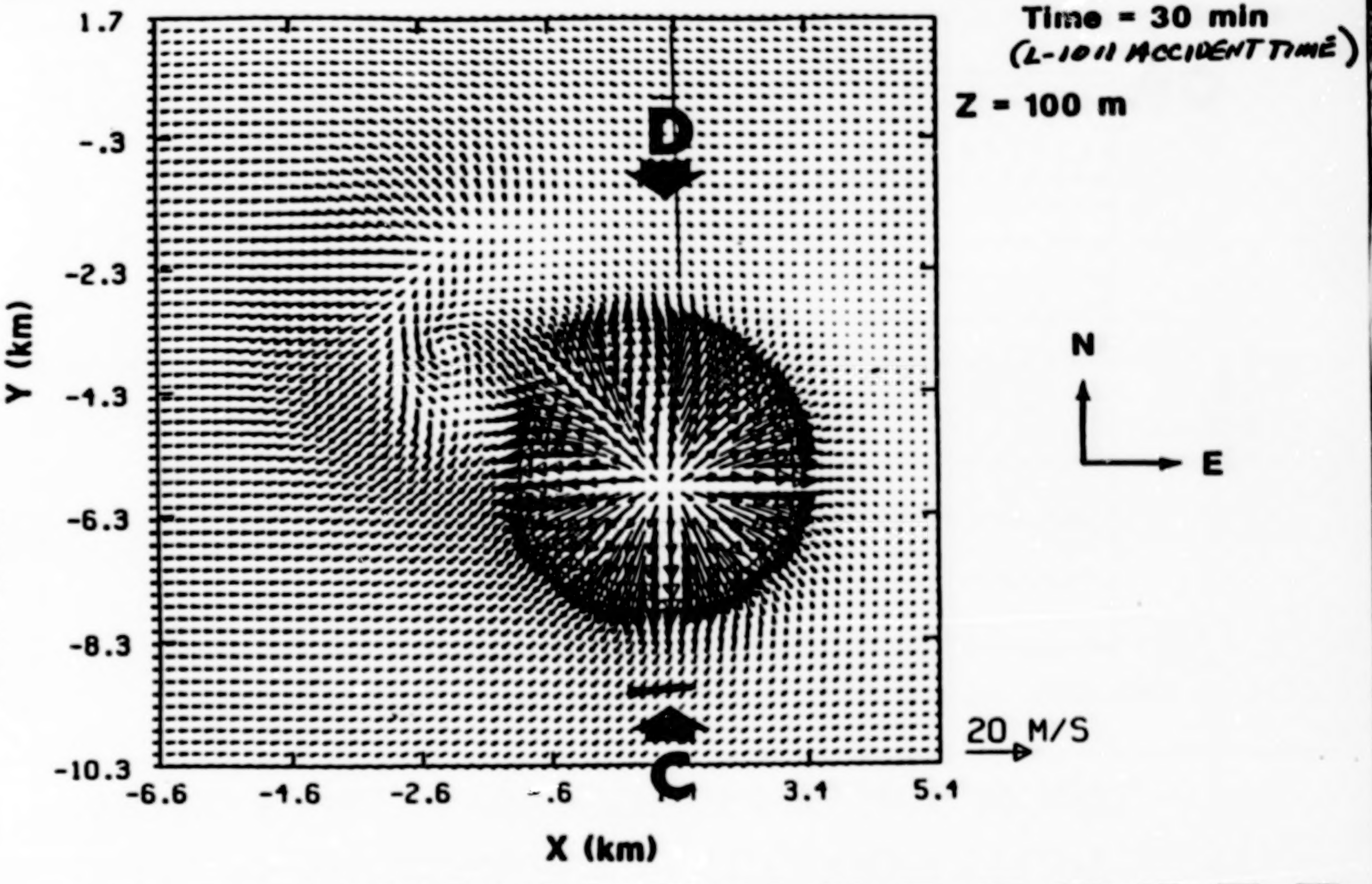

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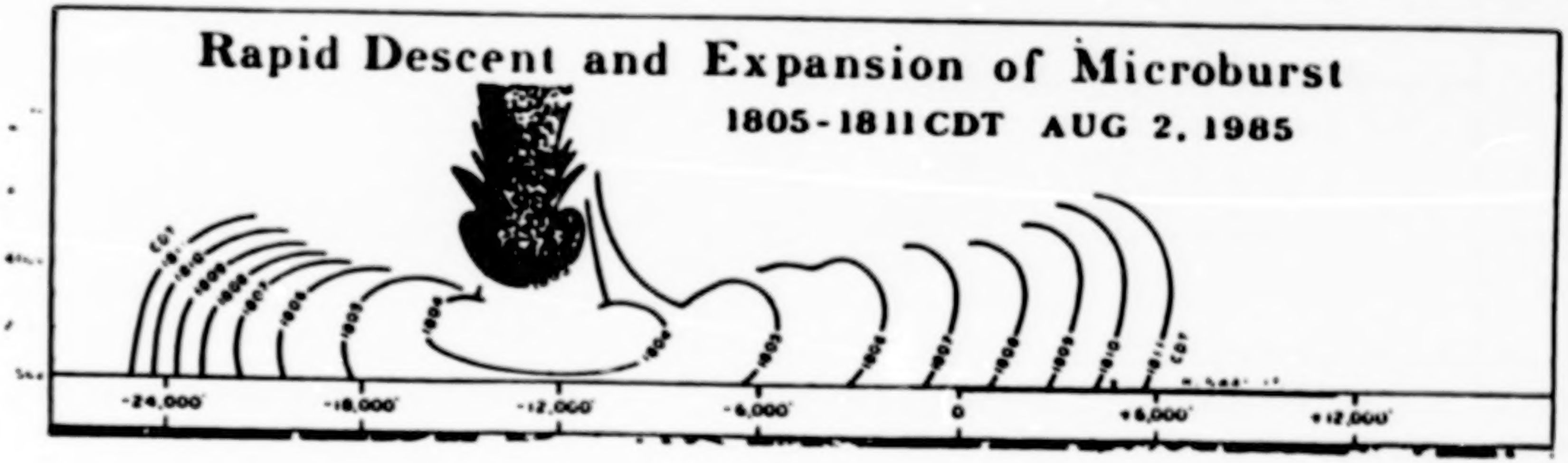

Rapid Descent and Expansion of Microburst

1805-1811 CDT AUG 2, 1985

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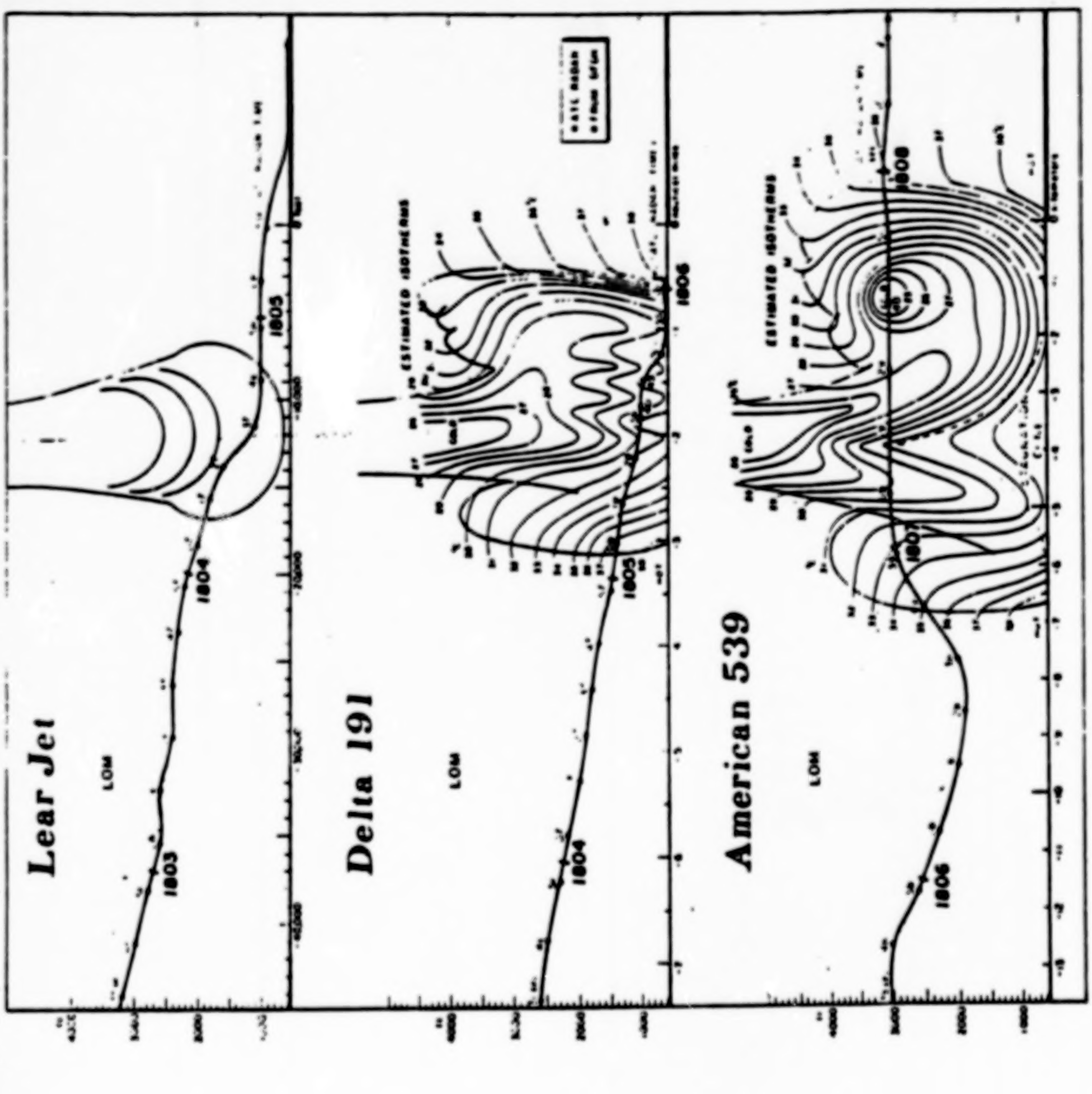

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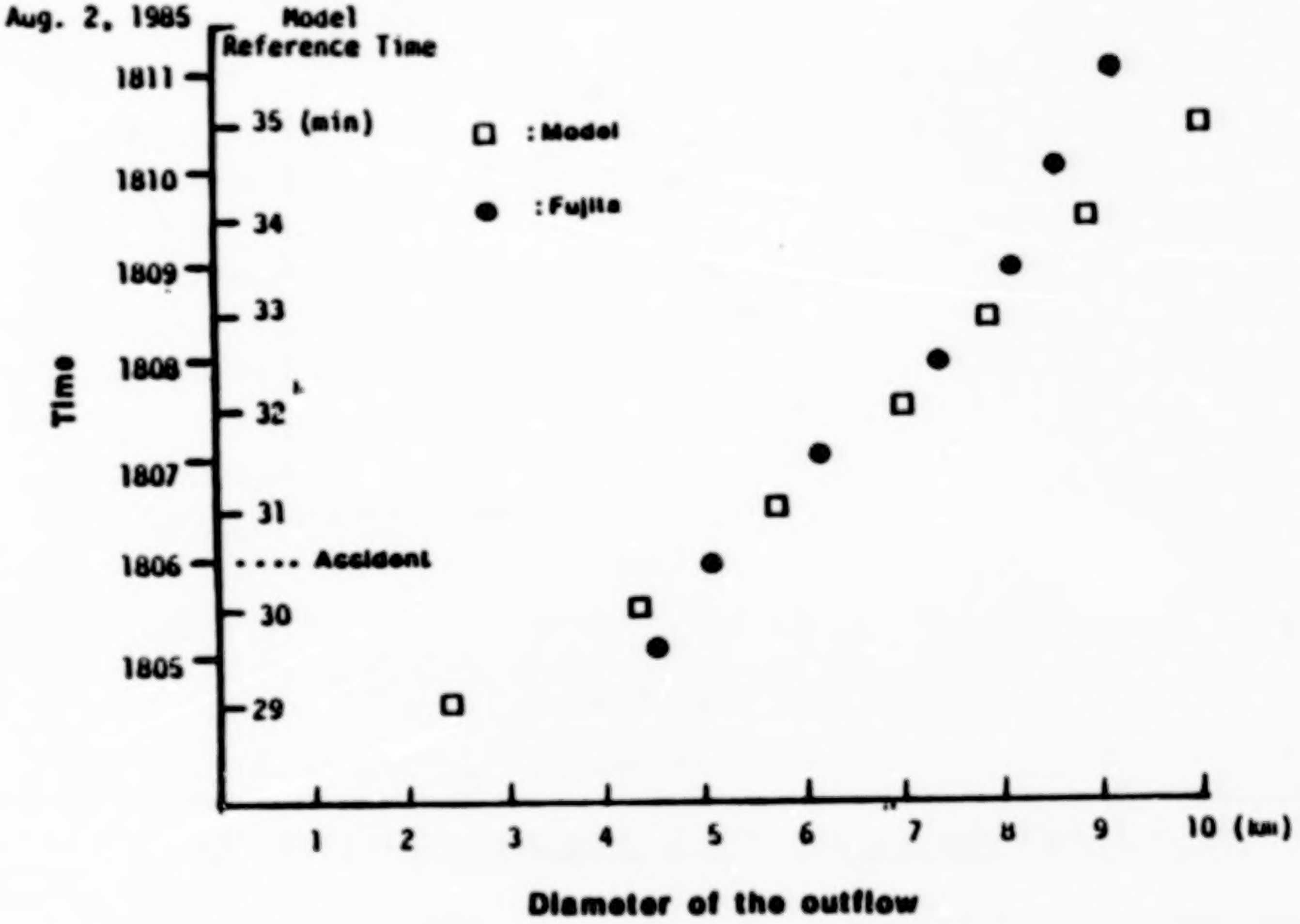
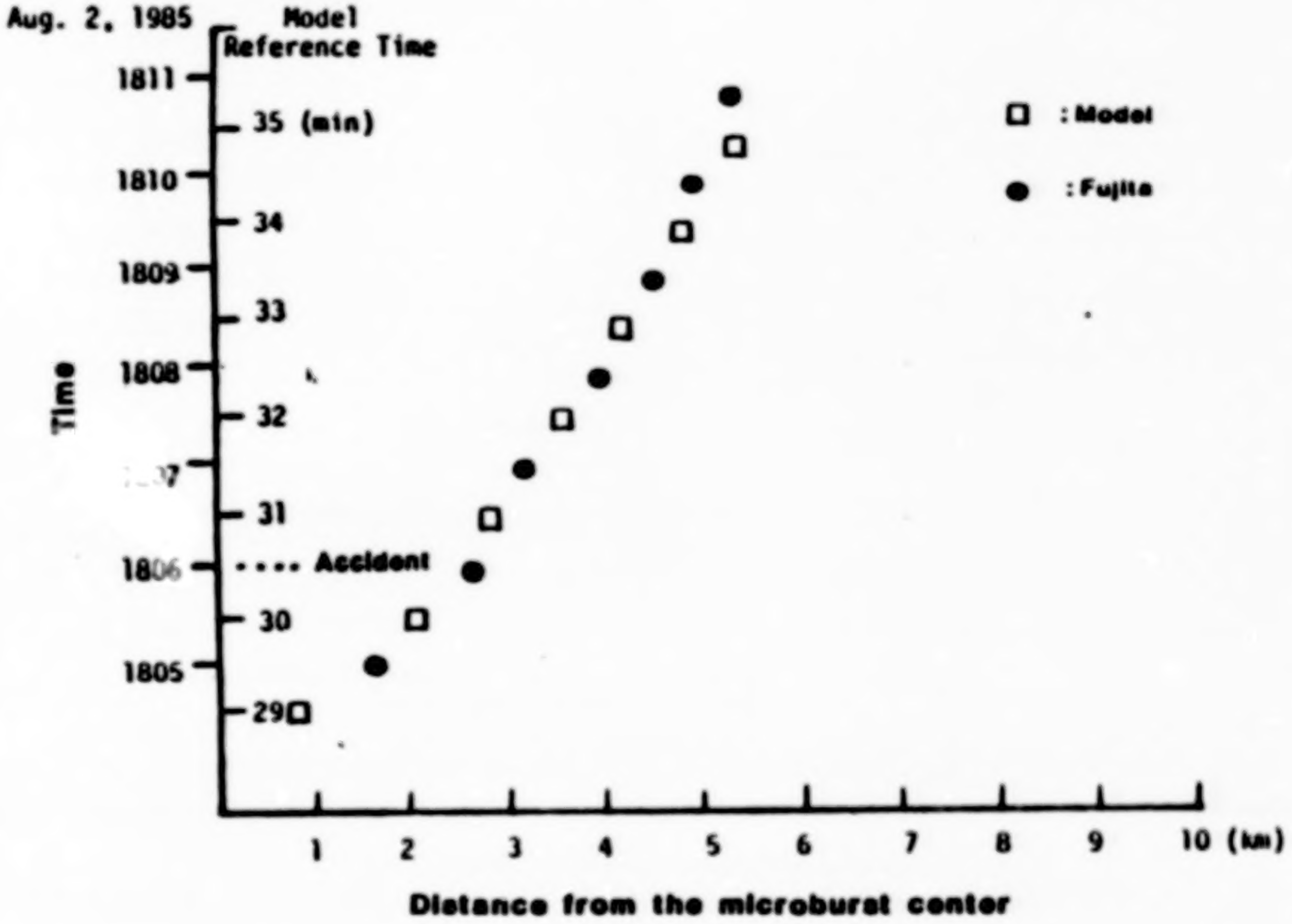
DIAMETER OF THE OUTFLOW REGION AT GROUND

Dallas Case Study



DISTANCE FROM THE INITIAL MICROBURST CENTER TO SOUTHERNMOST BOUNDARY OF OUTFLOW

Dallas Case Study

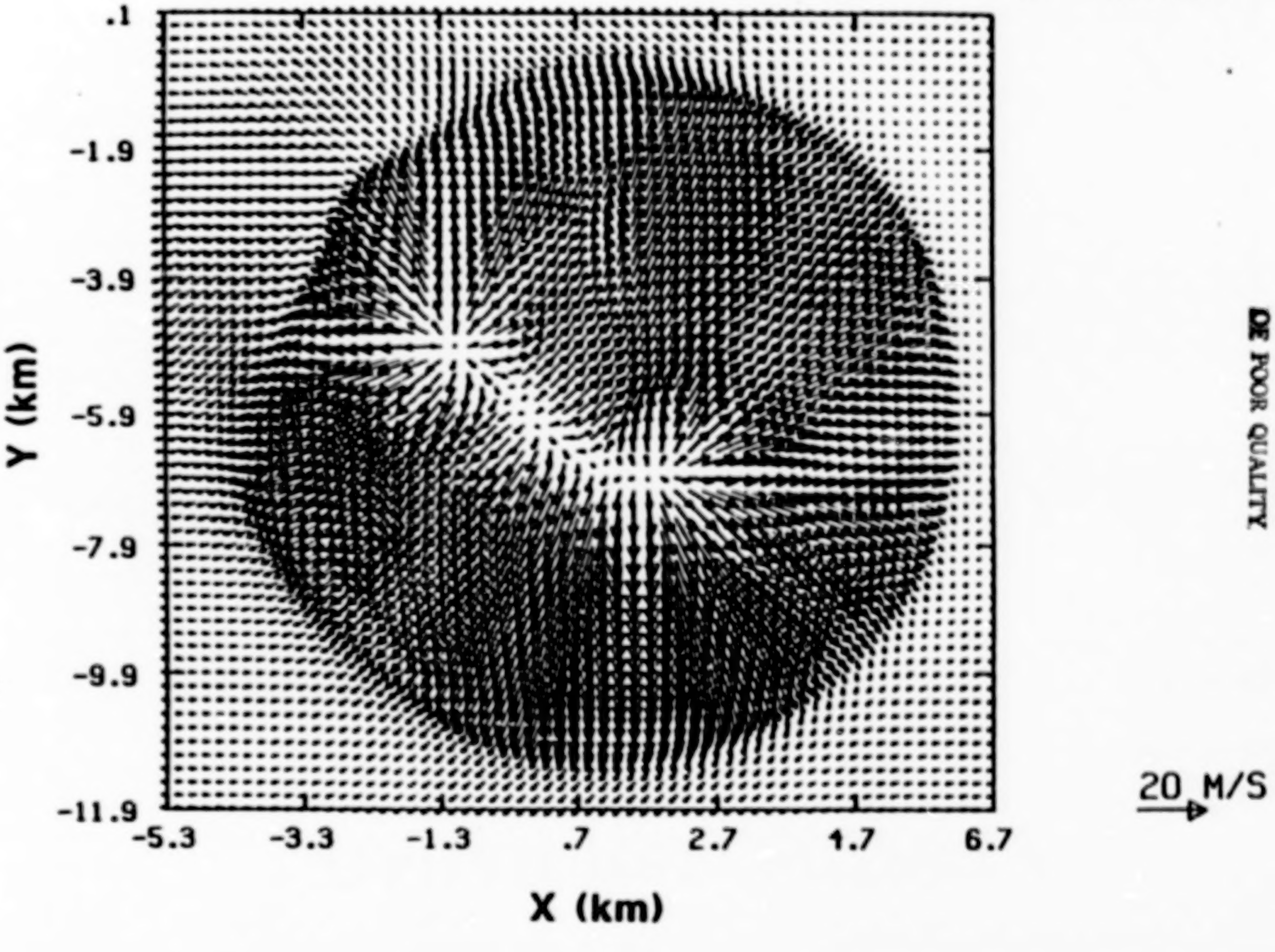


MACROBURST PHASE

Dallas Case Study

Time = 35 min

Z = 100 m



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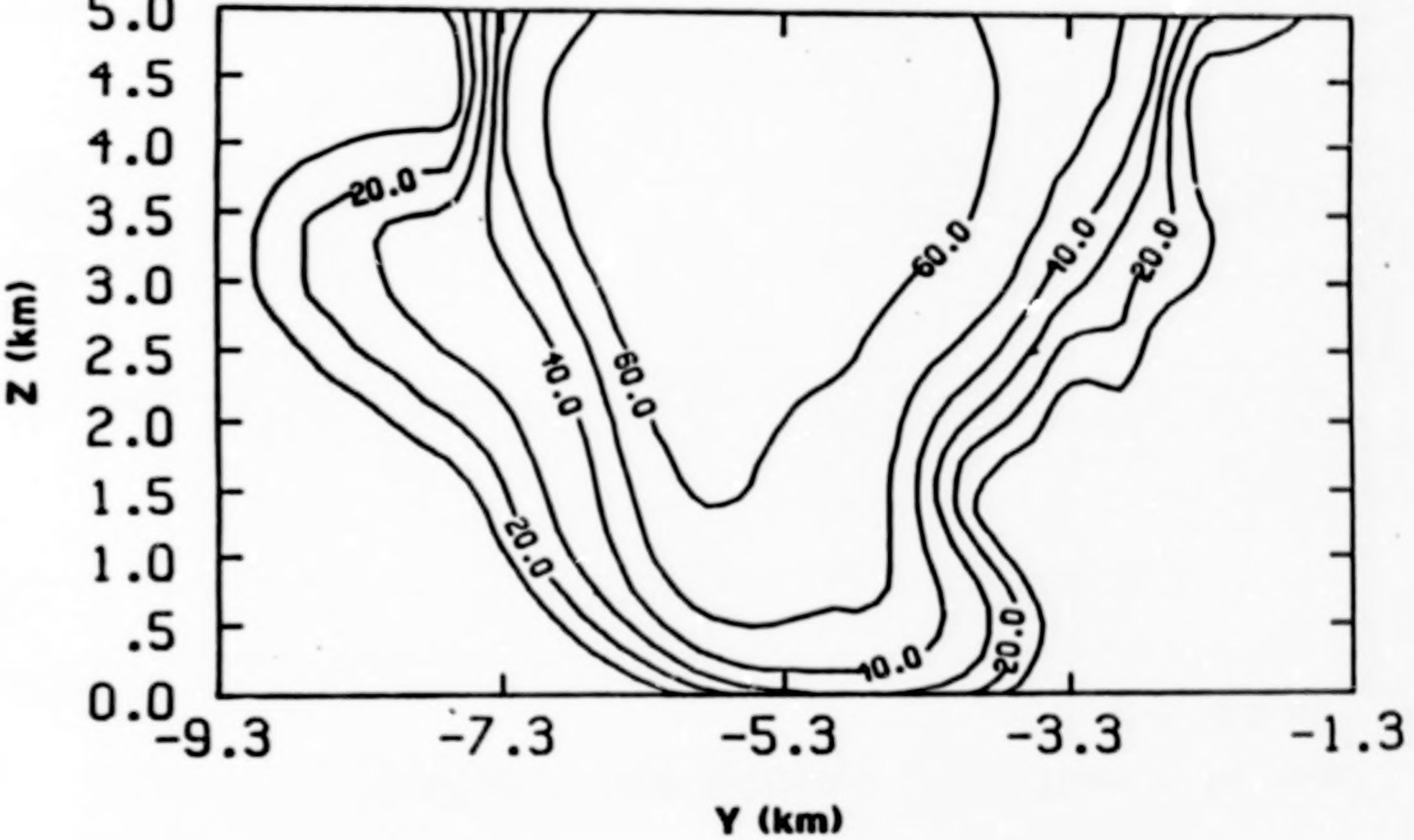
RADAR REFLECTIVITY

Dallas Case Study

Time = 28 min

X = 1.13 km

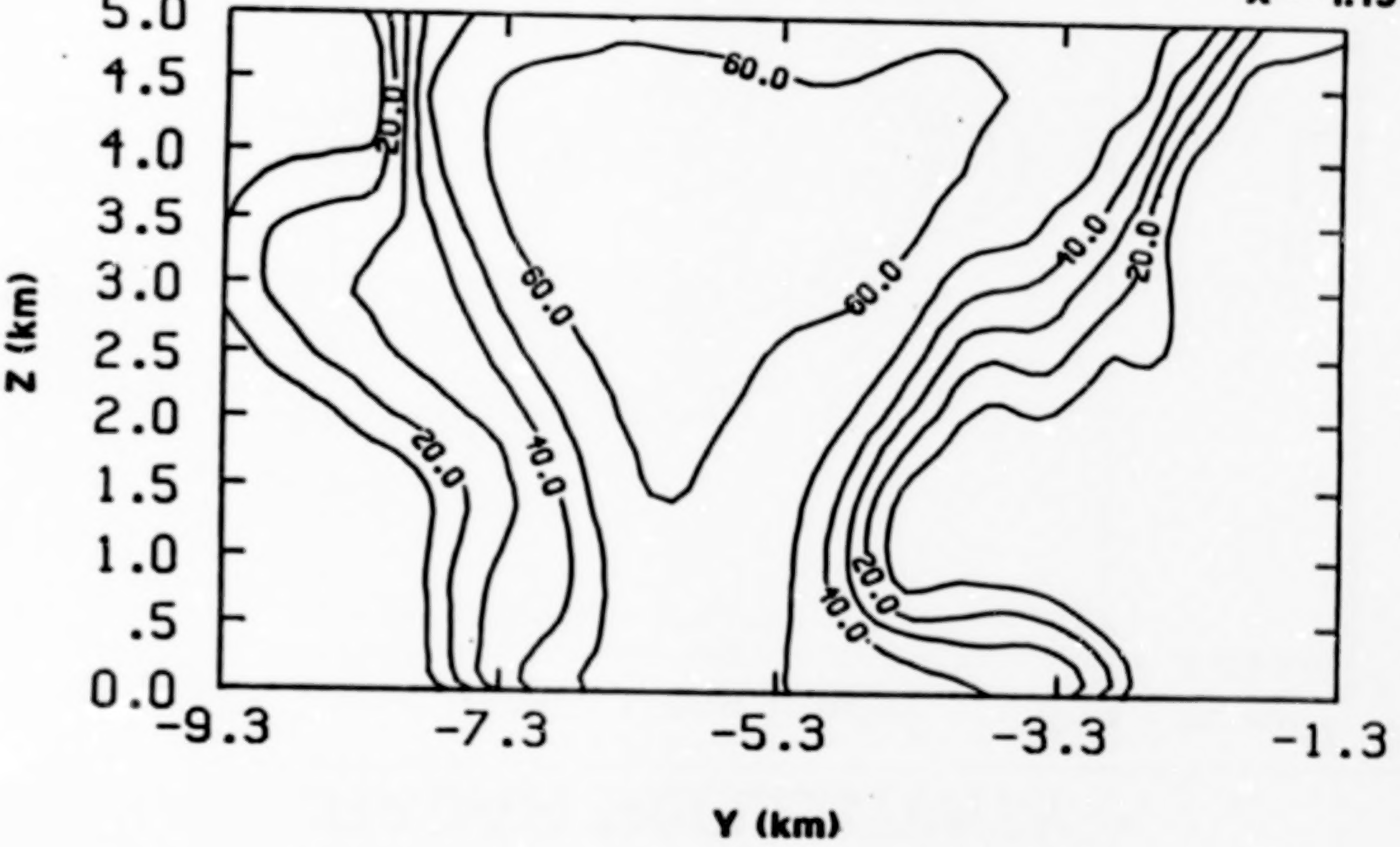


RADAR REFLECTIVITY

Dallas Case Study

Time = 30 min

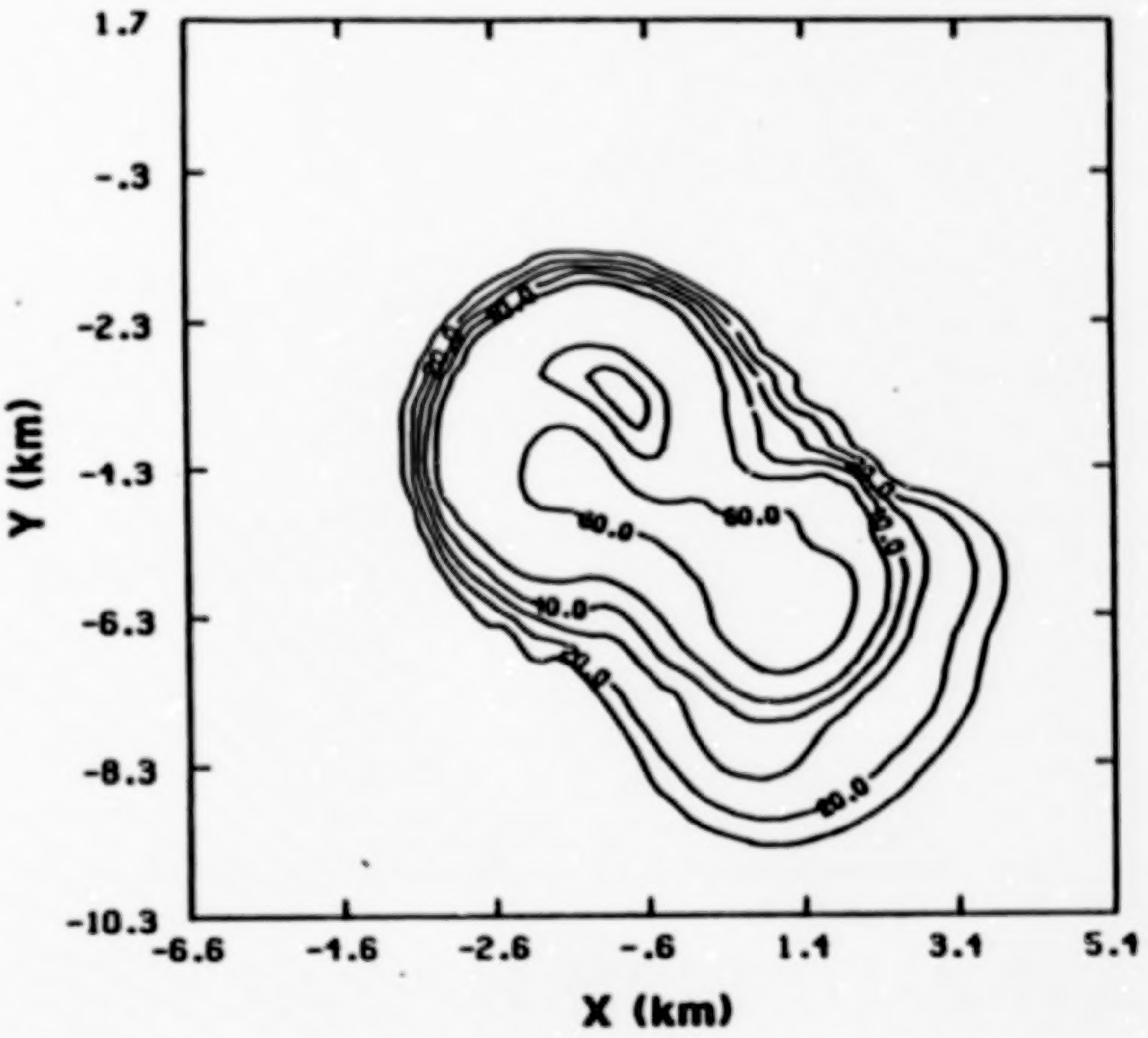
X = 1.19 km

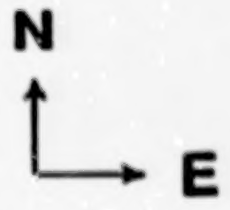


HORIZONTAL CROSS SECTION FOR RADAR REFLECTIVITY

Dallas Case Study

Time = 30 min
Z = 3.03 km





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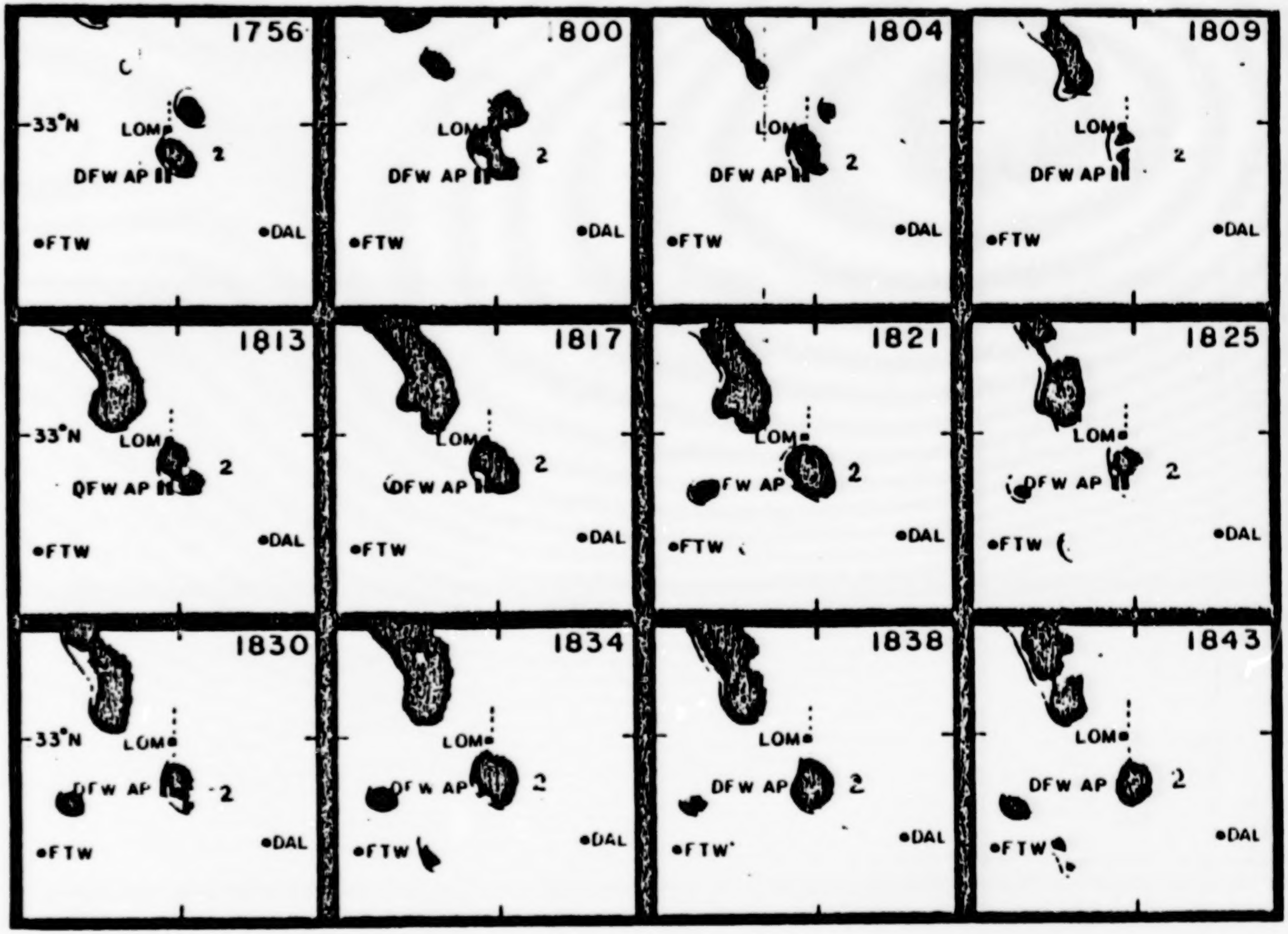
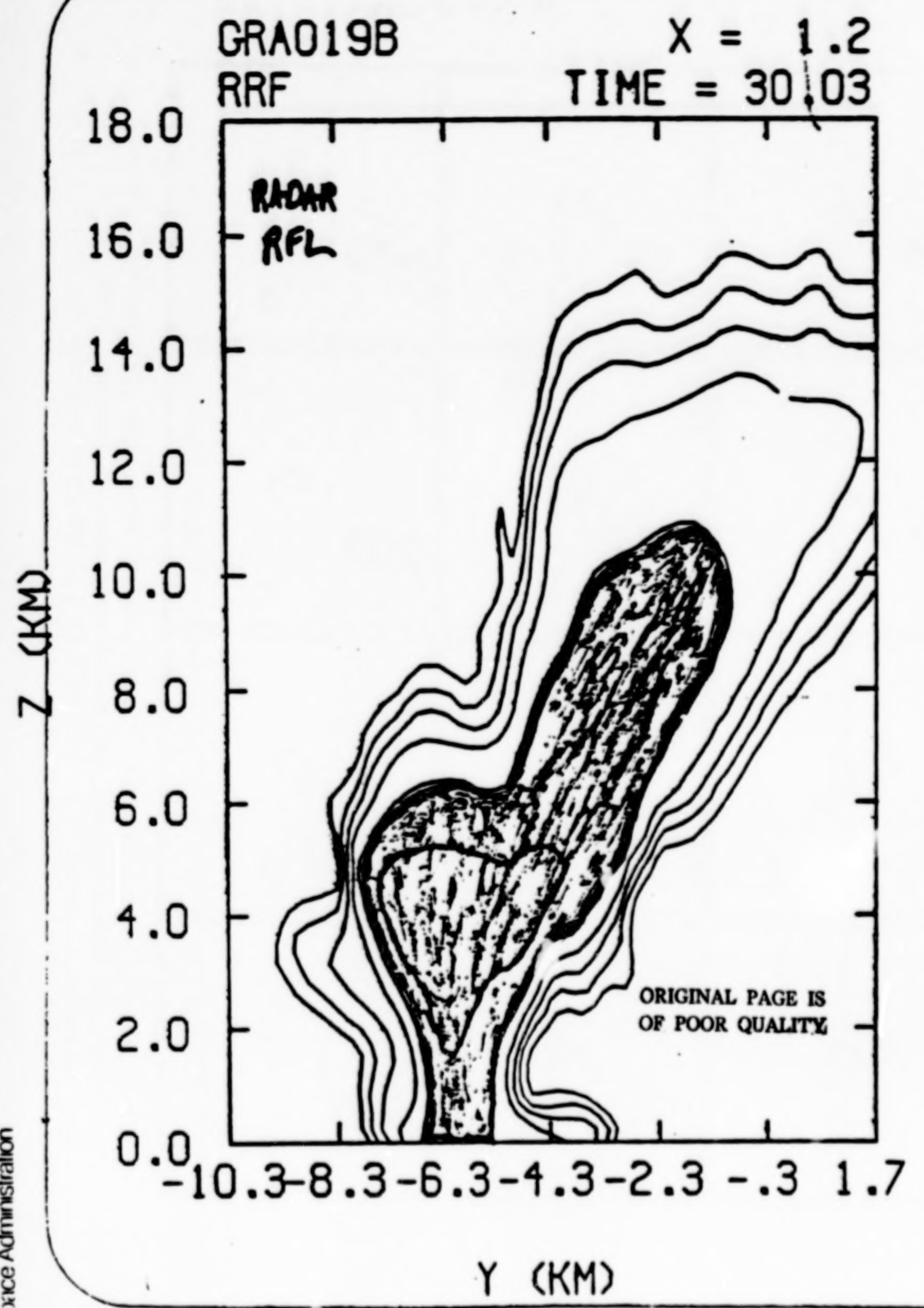


Fig. 1.9 A sequence of radar photos from the SEP radar, 75 n.m. southwest of DFW Airport. Of the five numbered echoes, Echo "2" induced two microbursts which are the DL 191 microburst and the 70-kt peak-gust



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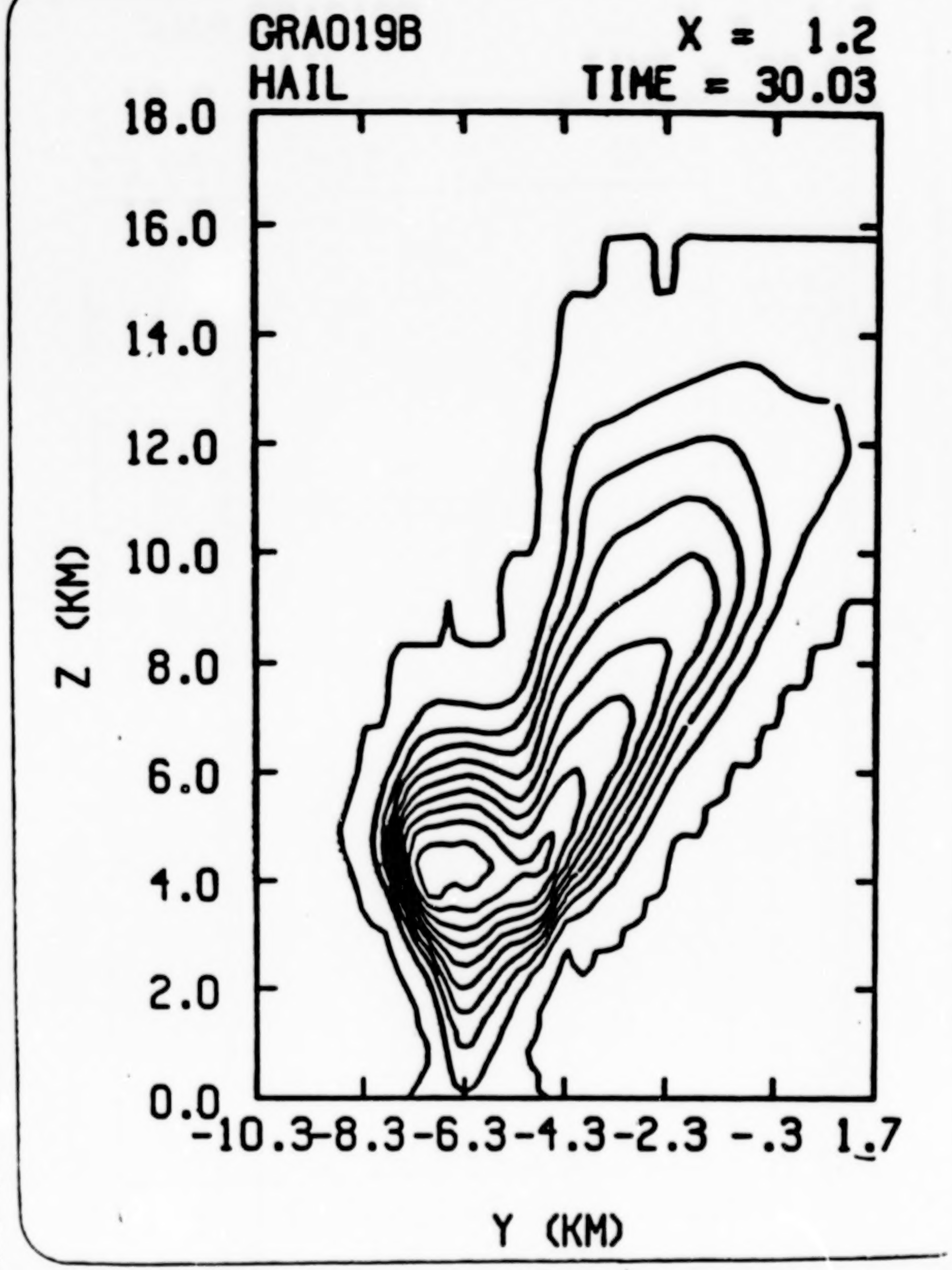
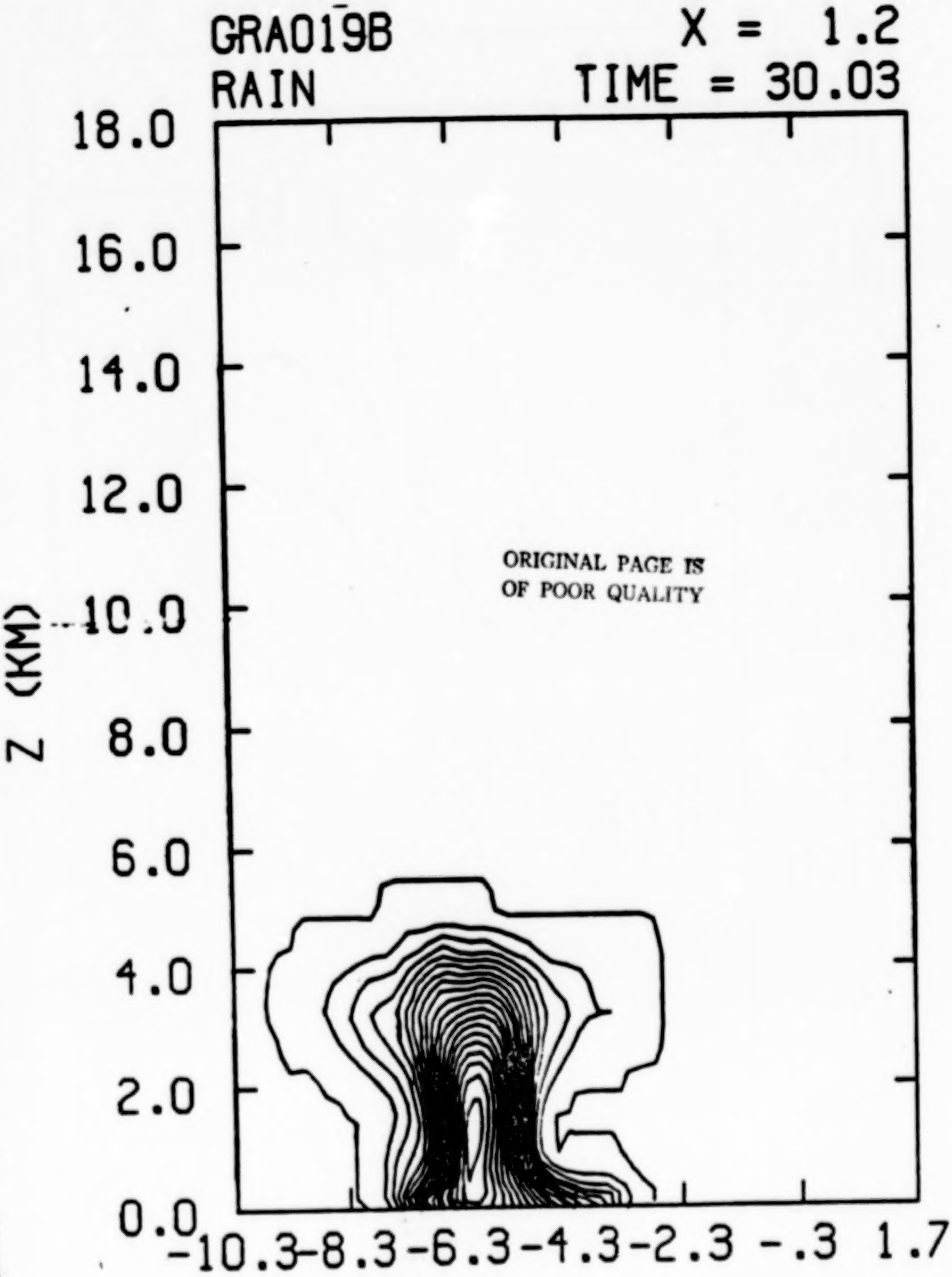


RAIN



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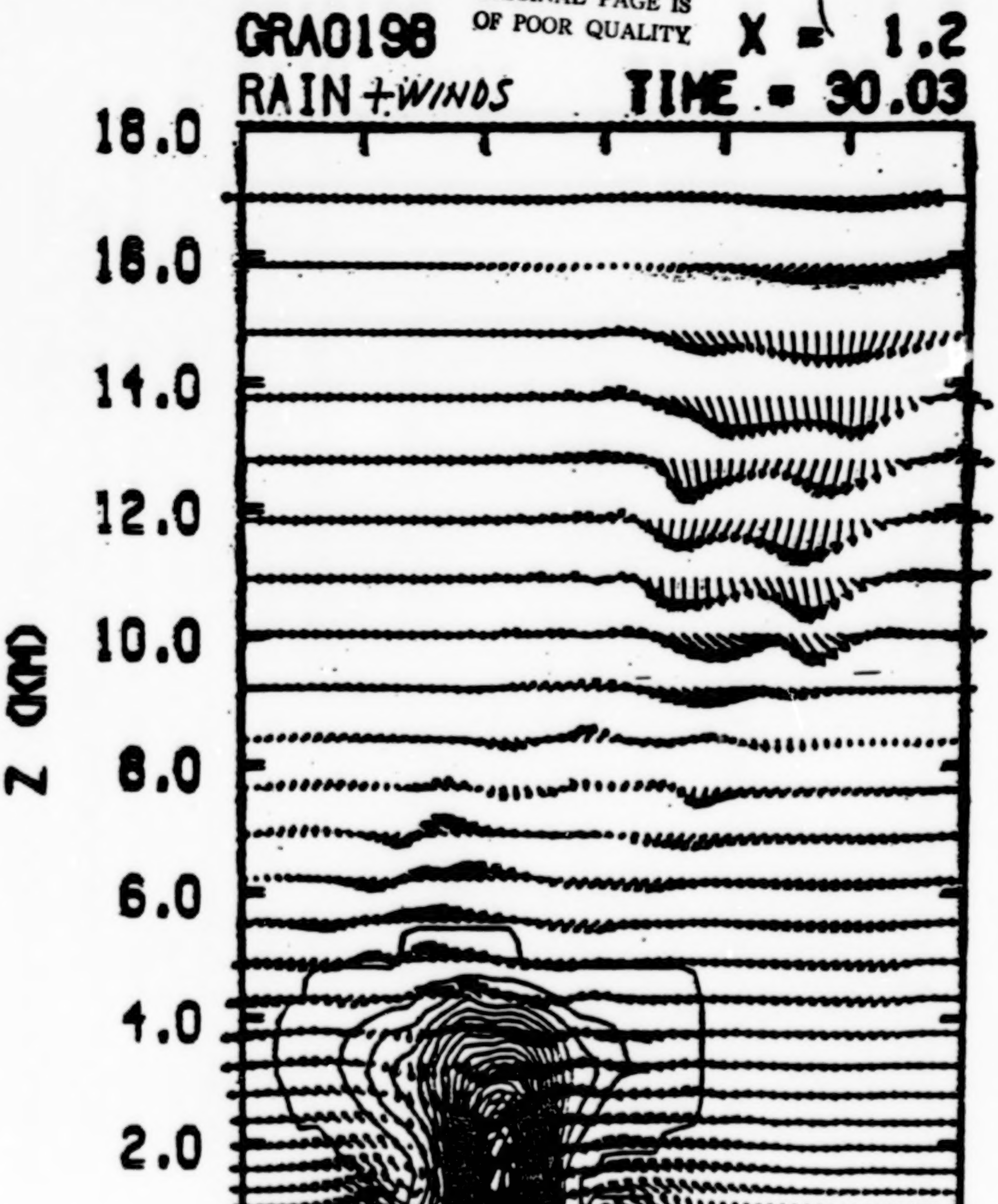

SUMMARY – DFW SIMULATION

- GOOD AGREEMENT BETWEEN SIMULATION AND AVAILABLE OBSERVATIONS
  - RATE OF OUTFLOW EXPANSION
  - SOUTHWARD GUST FRONT PROPAGATION
  - RADAR ECHO DIMENSIONS
  - RADAR ECHO INTENSITY
  - STORM HEIGHT
  - HAIL AND HEAVY RAINFALL AT SURFACE

- SIMULATION PRODUCES INTENSE MICROBURST WHICH EXPANDS INTO A MACROBURST CONTAINING MULTIPLE DOWNDRAFT CENTERS
  - MICROBURST SMALL IN HORIZONTAL SCALE BUT INTENSE
  - OUTFLOW IN EXCESS OF 40 KNOTS AT GROUND
  - PEAK DOWNDRAFTS IN EXCESS OF 30 KNOTS
  - RAPIDLY EXPANDING HORIZONTAL VORTEX RING

- DEMONSTRATES MODEL CAPABILITY

NASA AIRBORNE WIND SHEAR DETECTION AND AVOIDANCE PROGRAM

R. L. Bowles
NASA/LaRC

NASA AIRBORNE WIND SHEAR DETECTION AND AVOIDANCE PROGRAM

Presented To:

NASA/FAA/Industry/Universities
Sensor Technology
Review Meeting
February 24-25,1987

Dr. R.L. Bowles

THE WIND SHEAR THREAT

- O ENCOUNTERS INFREQUENT BUT HIGHLY SIGNIFICANT AVIATION HAZARD
- O CAUSAL FACTOR IN 27 U.S. ACCIDENTS (1964–1985)
- O CAUSE OF OVER 50% U.S. ACCIDENT FATALITIES (1975–1985)

AVIATION INDUSTRY CONSIDERS WIND SHEAR
A MAJOR SAFETY ISSUE

WIND SHEAR ACCIDENT STATISTICS

1962–1983

2 PER 10 MILLION TAKEOFFS AND LANDINGS ⟹ 1 ACCIDENT PER 200 DAYS AT CURRENT SCHEDULED OPERATION RATE

RECENT ACCIDENT HISTORY

1984 – DC-9 DETROIT
– 727 DENVER

1985 – L1011 DALLAS

≈ 1.8 ACCIDENTS/YEAR

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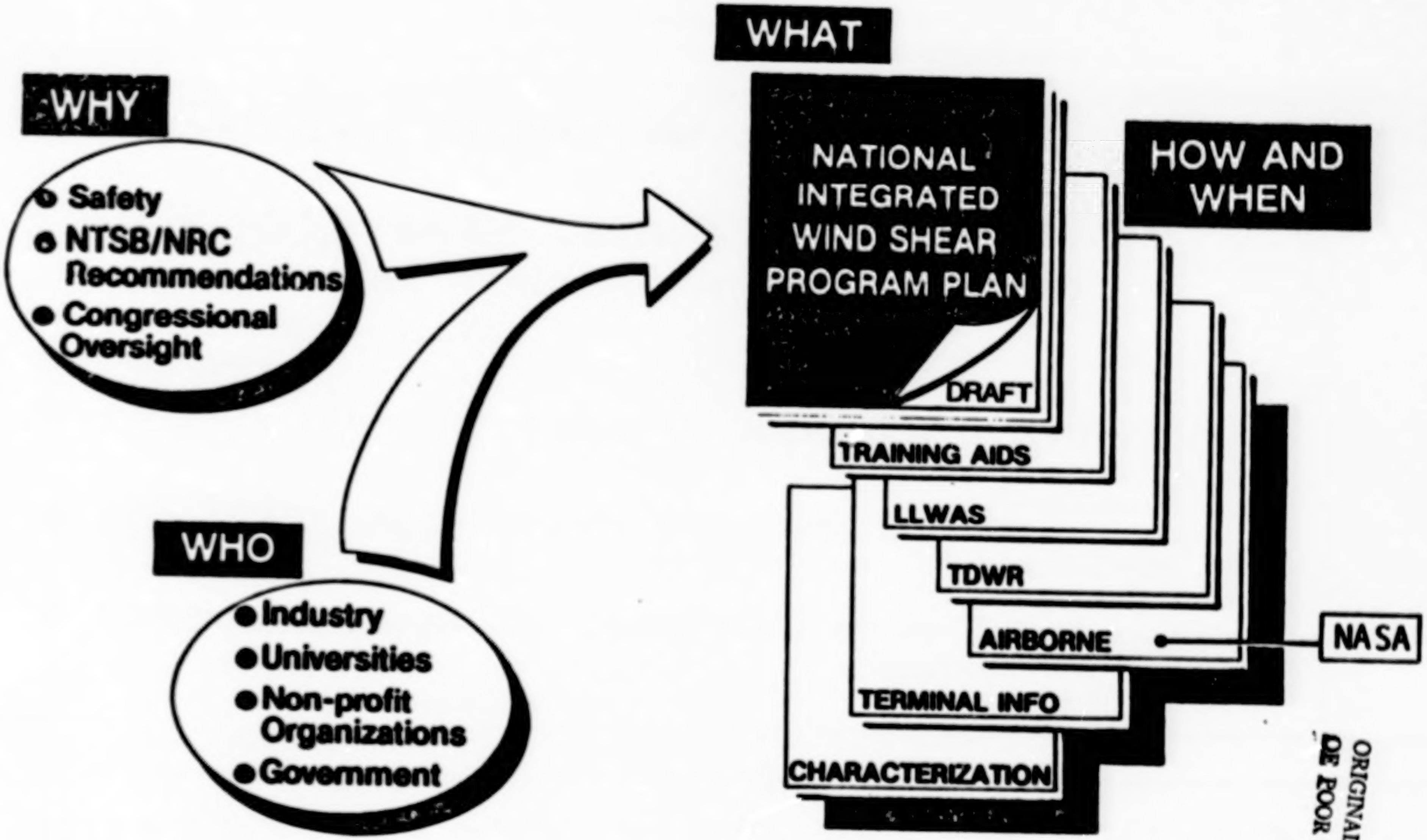

WHY

- Safety
- NTSB/NRC Recommendations
- Congressional Oversight

WHO

- Industry
- Universities
- Non-profit Organizations
- Government

WHAT

NATIONAL INTEGRATED WIND SHEAR PROGRAM PLAN

DRAFT

HOW AND WHEN

- TRAINING AIDS
- LLWAS
- TDWR
- AIRBORNE — NASA
- TERMINAL INFO
- CHARACTERIZATION

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INTEGRATED FAA WIND SHEAR PROGRAM

- EDUCATION/TRAINING OPERATING PROCEDUES
- LOW LEVEL WIND SHEAR ALERTING SYSTEM
- AIRPORT TERMINAL DOPPLER WEATHER RADAR
- AIRBORNE SYSTEMS
    - INDUSTRY DEVELOPMENTS (NEAR TERM)
    - FAA/NASA PROGRAM (FAR TERM)
- HAZARD CHARACTERIZATION

NASA/FAA AIRBORNE WIND SHEAR PROGRAM

OBJECTIVE

DEVELOP AND DEMONSTRATE TECHNOLOGY
FOR LOW ALTITUDE WIND SHEAR RISK REDUCTION
THROUGH AIRBORNE DETECTION, WARNING,
AVOIDANCE AND SURVIVABILITY

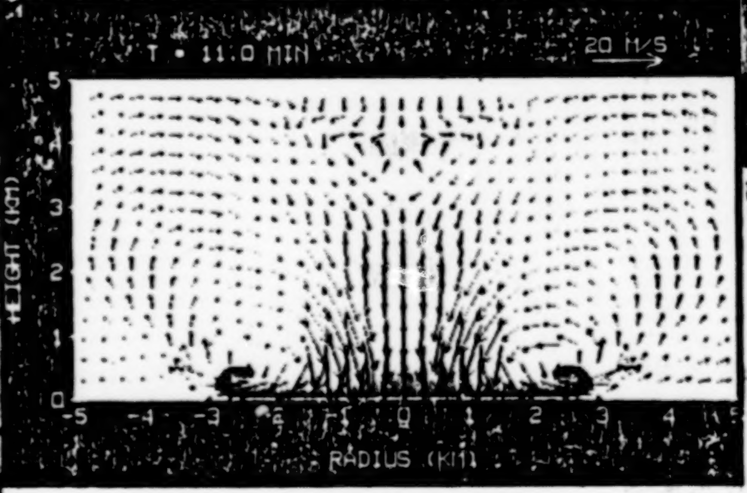
OPERATIONAL REQUIREMENT

- AIRBORNE CAPABILITY THAT PROMOTES FLIGHT CREW AWARENESS OF THE PRESENCE OF WIND SHEAR OR MICROBURST PHENOMENA WITH ENOUGH TIME TO AVOID THE AFFECTED AREA OR ESCAPE FROM THE ENCOUNTER

STRONG GOVERNMENT/INDUSTRY INTERPLAY

NASA/FAA AIRBORNE WIND SHEAR PROGRAM ELEMENTS

Hazard Characterization



- Wind shear physics/modeling
- Heavy rain aerodynamics
- Impact on flight characteristics

Sensor Technology

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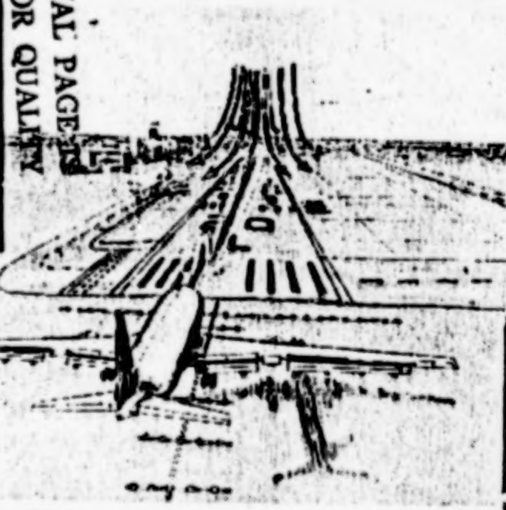
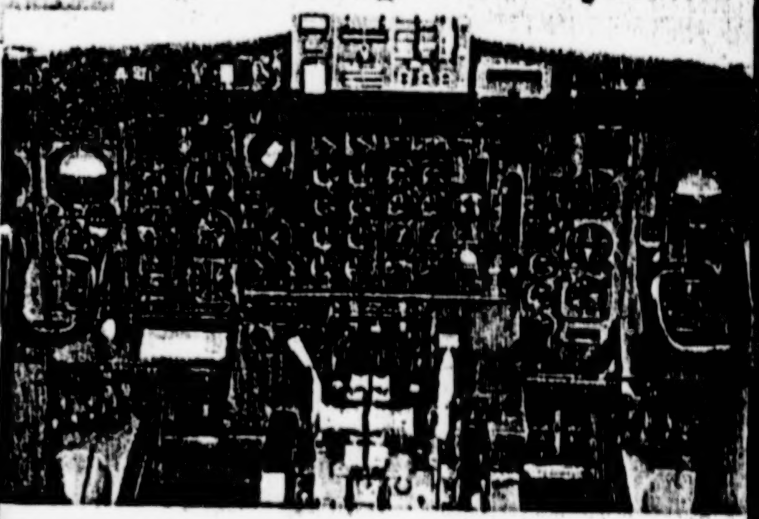


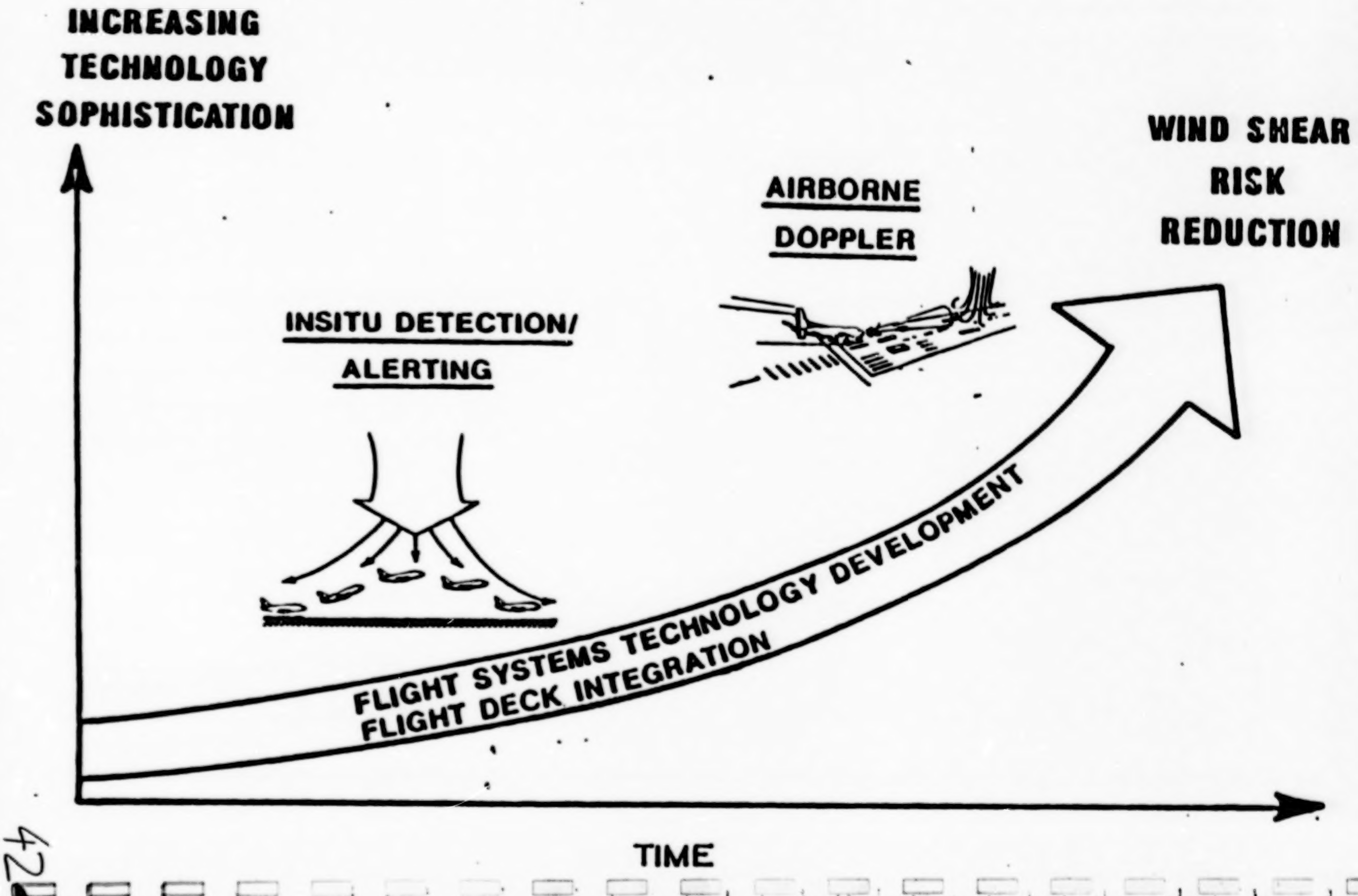
- INSITU
- Airborne doppler radar/LIDAR
- Sensor fusion

Flight Management Systems



- System performance requirements
- Guidance/display concepts
- Pilot factors/procedures

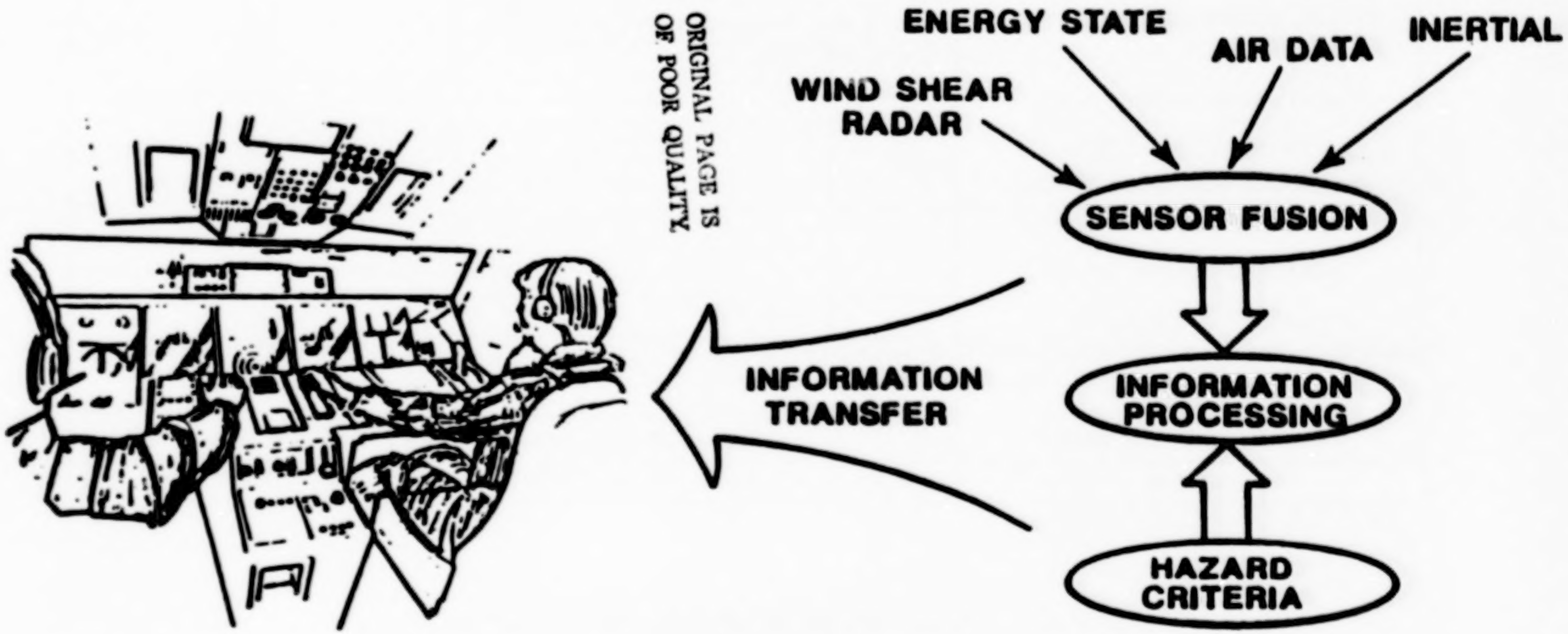
TECHNOLOGY INTEGRATION ROADMAP



WIND SHEAR DETECTION/WARNING
AND
AVOIDANCE SYSTEM

FLIGHT DECK INTEGRATION

FLIGHT SYSTEMS TECHNOLOGY



ENERGY STATE

AIR DATA

INERTIAL

WIND SHEAR RADAR

SENSOR FUSION

INFORMATION PROCESSING

HAZARD CRITERIA

INFORMATION TRANSFER

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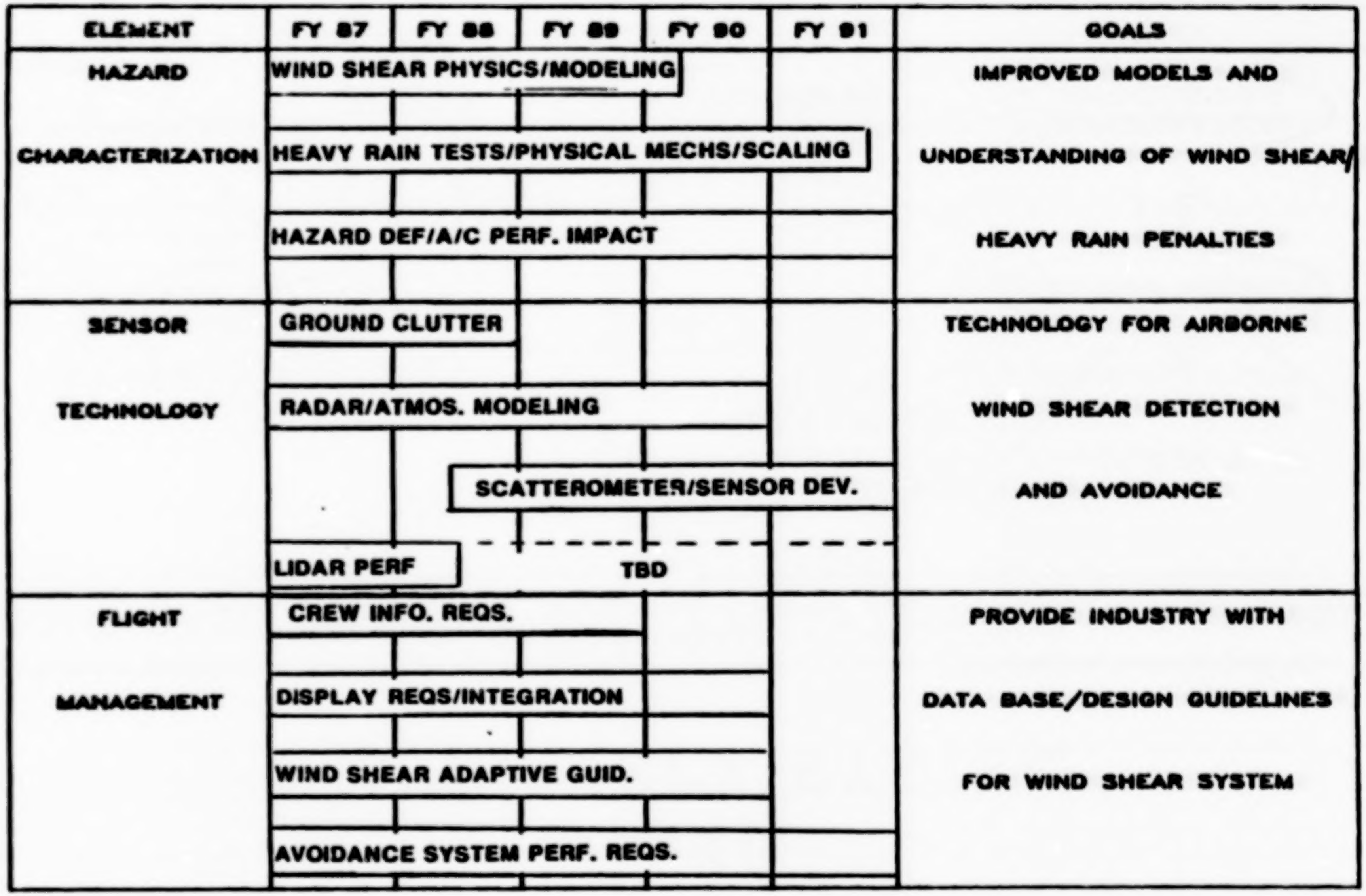
NASA/FAA WIND SHEAR PROGRAM



ELEMENT	FY 87	FY 88	FY 89	FY 90	FY 91	GOALS
HAZARD	WIND SHEAR PHYSICS/MODELING					IMPROVED MODELS AND
CHARACTERIZATION	HEAVY RAIN TESTS/PHYSICAL MECHS/SCALING					UNDERSTANDING OF WIND SHEAR/
	HAZARD DEF/A/C PERF. IMPACT					HEAVY RAIN PENALTIES
SENSOR	GROUND CLUTTER					TECHNOLOGY FOR AIRBORNE
TECHNOLOGY	RADAR/ATMOS. MODELING					WIND SHEAR DETECTION
		SCATTEROMETER/SENSOR DEV.				AND AVOIDANCE
	LIDAR PERF		TBD			
FLIGHT	CREW INFO. REQS.					PROVIDE INDUSTRY WITH
MANAGEMENT	DISPLAY REQS/INTEGRATION					DATA BASE/DESIGN GUIDELINES
	WIND SHEAR ADAPTIVE GUID.					FOR WIND SHEAR SYSTEM
	AVOIDANCE SYSTEM PERF. REQS.					

REMOTE AIRBORNE WIND SHEAR DETECTION

CANDIDATE SENSOR TECHNOLOGIES

DOPPLER RADAR	DOPPLER LIDAR	INFRARED RADIOMETER
O RAIN DROP TRACERS	O AEROSOL TRACERS	O THERMAL GRADIENT
O DIRECT WIND MEASUREMENTS	O DIRECT WIND MEASUREMENTS	O INFERENTIAL WIND MEASUREMENTS
O NASA FLIGHT EXP. - 1982	O NASA FLIGHT EXPS. - 1981-84	O 1000 HRS IN NASA AIRCRAFT
O 1970'S TECHNOLOGY	O 1970'S TECHNOLOGY	O 1980'S TECHNOLOGY
O WIND SHEAR PERFORMANCE (PREDICTION RATE) UNKNOWN	O WIND SHEAR PERFORMANCE (PREDICTION RATE) UNKNOWN	O 98% PREDICTION RATE/CAT 83% PREDICTION RATE/LLWS
O MOVING GROUND CLUTTER CHIEF PROBLEM	O ABSORPTION/BACKSCATTER PROPERTIES FOR 1.5 - 10.6 MICRON AND HARDWARE COMPLEXITY CHIEF PROBLEMS	O POTENTIAL LIMITED BY INFERENTIAL MEASUREMENTS

BOWLES/REM AIR WS DET

AIRBORNE WIND SHEAR AVOIDANCE SYSTEMS

A SENSORS ABILITY TO DETECT CONDITIONS THAT ARE CONDUCTIVE TO HAZARDOUS WIND SHEAR IMPLIES THAT THE SENSORS CAN OPERATE IN HEAVY PRECIPITATION AS WELL AS CLEAR AIR.

	RADAR	LIDAR	INFRARED
WET	VERY GOOD POTENTIAL	POOR	MARGINAL
DRY	POOR	GOOD POTENTIAL	GOOD POTENTIAL
BASE TECHNOLOGY READINESS	IN-HAND	NEAR FUTURE	NEAR FUTURE

HYBRID SYSTEM MAY BE THE ANSWER.

WHO IS DOING WHAT?

AIRBORNE REMOTE WIND SHEAR DETECTION

	RADAR	LIDAR	INFRARED
INDUSTRY	O NEW GENERATION DOPPLER WX-RADAR	O DEVELOPMENTS IN SOLID STATE AND GAS LASERS	O NEW GENERATION SENSOR
NASA	O TECHNICAL FEASIBILITY FOR WIND SHEAR DETECTION	O SUPPORT FOR PERFORMANCE/TECHNOLOGY ASSESSMENT	O PROVIDE DATA TO PROMOTE PERFORMANCE/ TECHNOLOGY ASSESSMENT

NASA/FAA AIRBORNE WIND SHEAR PROGRAM

SPECIFIC PAYOFFS

- REMOTE DETECTION AHEAD OF AIRCRAFT HAS DISTINCT ADVANTAGES
  - FOR AIRPORTS NOT PROTECTED BY TDWR
  - SUPPLEMENTS TDWR WHERE TDWR EXISTS
- PROMOTE AND ACCELERATE DEVELOPMENT OF AIRBORNE REMOTE SENSOR TECHNOLOGY
- SENSOR FUSION CONCEPT PROVIDES FOR REDUNDANCY OF INSITU DETECTION AND ALERTING FOR CASES WHERE RADAR INEFFECTIVE
- SYSTEMS APPROACH MAY FOSTER EARLY ACCEPTANCE BY AVIATION COMMUNITY
- PROVIDES INDUSTRY WITH ENGINEERING DATA BASE AND DESIGN GUIDELINES FOR USE IN DEVELOPMENT AND MANUFACTURE OF CERTIFIABLE AIRBORNE WIND SHEAR SYSTEMS
- REALISTIC PROTECTION SYSTEM — FLY FLYABLE SHEARS/AVOID UNFLYABLE SHEARS

INDUSTRY/NASA LIDAR ACTIVITIES

STATUS

- O TECHNICAL DISCUSSIONS WITH INDUSTRY AS REGARDS LIDAR WIND SHEAR POTENTIAL
  - o LOCKHEED
  - o SPECTRA TECH.
  - o COHERENT TECHNOLOGY
- O PHASE I EFFORT IDENTIFIED
  - o NASA WILL SUPPORT A PERFORMANCE/TECHNOLOGY ASSESSMENT STUDY
  - o EMPHASIS ON TRADE STUDIES FOR BOTH SOLID STATE AND GAS LASER SYSTEMS
  - o NASA WILL LEVEL PLAYING FIELD BY PROVIDING CONVECTIVE WIND SHEAR DATA BASE AND "STRAWMAN" HAZARD INDEX
  - o TECHNICAL APPROACH PARALLELS NASA RADAR PROGRAM
- O PHASE II TBD BASED ON PHASE I FINDINGS AND IN-HOUSE PLANNING EXERCISE

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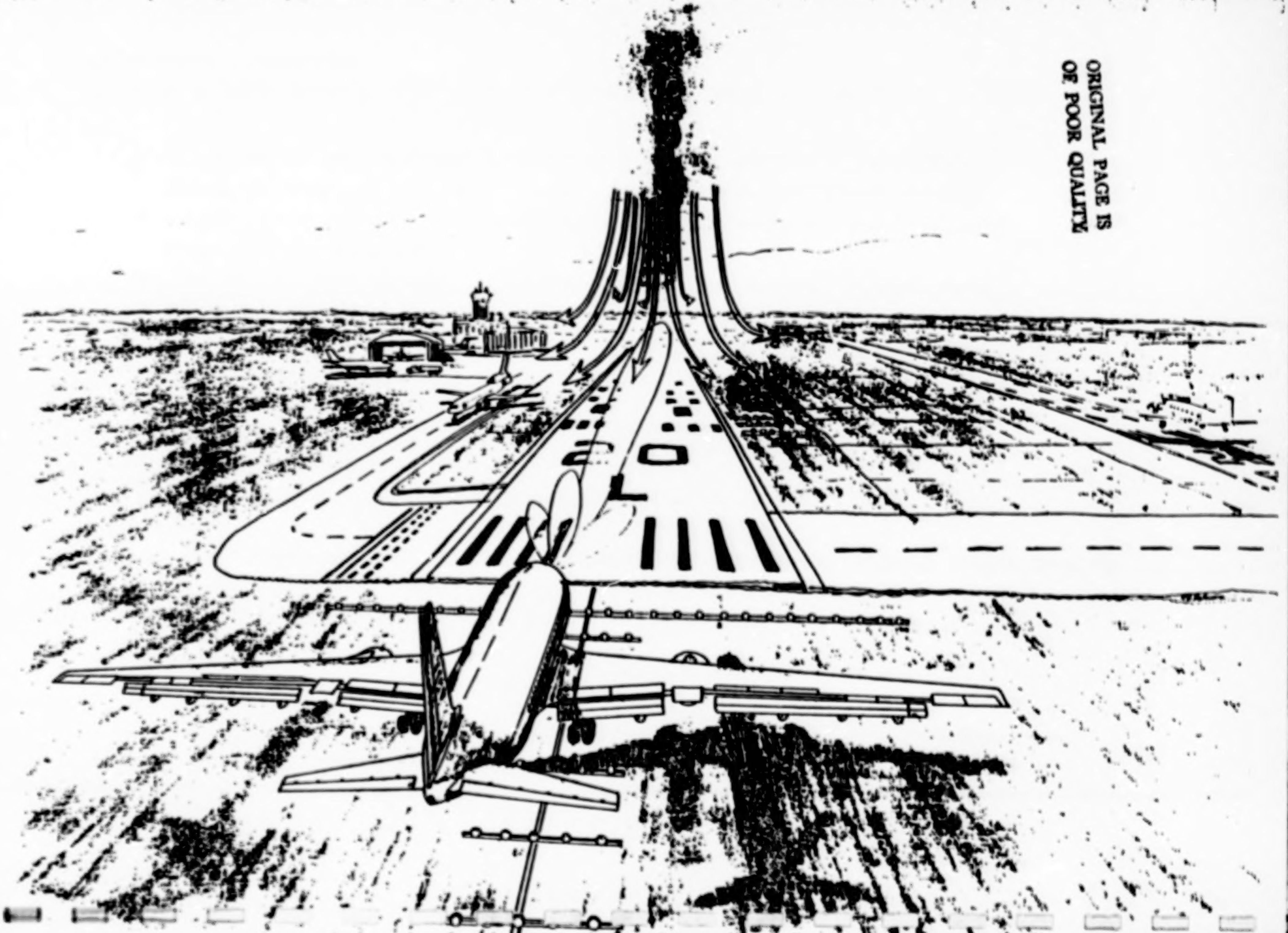


PROGRAM STATUS

- NASA ROLE IN SUPPORT OF NATIONAL WIND SHEAR EFFORT IDENTIFIED
- MOU SIGNED BY NASA AND FAA WHICH ESTABLISHES 5–YR COOPERATIVE PROGRAM
- PRORAM ELEMENTS/FACILITIES/RESOURCE REQUIREMENTS FINALIZED
- PROJECTED FY 87 BUDGET ADEQUATE DUE TO FAA FY 86 RESOURCE FRONT LOADING
- FUNDING SHORTFALL IN OUT YEARS (1988–1991)

AAC COMMENTS REGARDING WIND SHEAR/HEAVY RAIN RESEARCH – APRIL 10, 1986

- GOOD WORK
- CORRECT, BROADLY APPLICABLE APPROACH
- NEED FOR LONG TERM EFFORT AS OPPOSED TO REACTIVE EFFORT

SUMMARY

- O AVIATION COMMUNITY NEEDS SOLUTIONS
- O FAA CHARGED TO PROVIDE SOLUTIONS THROUGH NATIONAL TECHNICAL MEANS
- O NASA ROLE IDENTIFIED
- O JOINT NASA/FAA PROGRAM IN PLACE

WIND SHEAR DETECTION, WARNING AND FLIGHT GUIDANCE

R. L. Bowles
NASA/LaRC

WIND SHEAR DETECTION, WARNING AND FLIGHT GUIDANCE

Presented At:

NASA/FAA/Industry/Universities
Sensor Technology
Review Meeting
February 24-25,1987

Dr. R.L. Bowles

FY–87 KEY ACTIVITIES

FLIGHT MANAGEMENT SYSTEMS

- SYSTEM PERFORMANCE REQUIREMENTS FOR WIND SHEAR DETECTION, WARNING AND AVOIDANCE
  - PRESENT POSITION REACTIVE
    - HAZARD INDEX/THRESHOLDS
    - ANNUNCIATION AND INFORMATION DISPLAY
  - FORWARD LOOK PREDICTIVE
    - SIMULATION OF MICROBURST ENCOUNTER DYNAMICS WITH "PERFECT" FORWARD LOOK SENSOR
    - INFORMATION REQUIREMENTS FOR AVOIDANCE

- FLIGHT GUIDANCE FOR WIND SHEAR RECOVERY AND ESCAPE
  - PRESENT POSITION ALERT AND WARNING
  - SIMULATOR EVALUATION OF NASA DEVELOPED GUIDANCE TECHNIQUES
    - CONVENTIONAL COCKPIT DISPLAY/FLIGHT DIRECTOR PITCH COMMAND
    - ADVANCED COCKPIT FLIGHT PATH SITUATION DISPLAY/GAMMA COMMAND

WIND SHEAR IMPACT ON AIRCRAFT PERFORMANCE

O ENERGY STATE

$$h_p = \frac{E}{W} = \frac{V^2}{2g} + h$$

O POTENTIAL CLIMB RATE

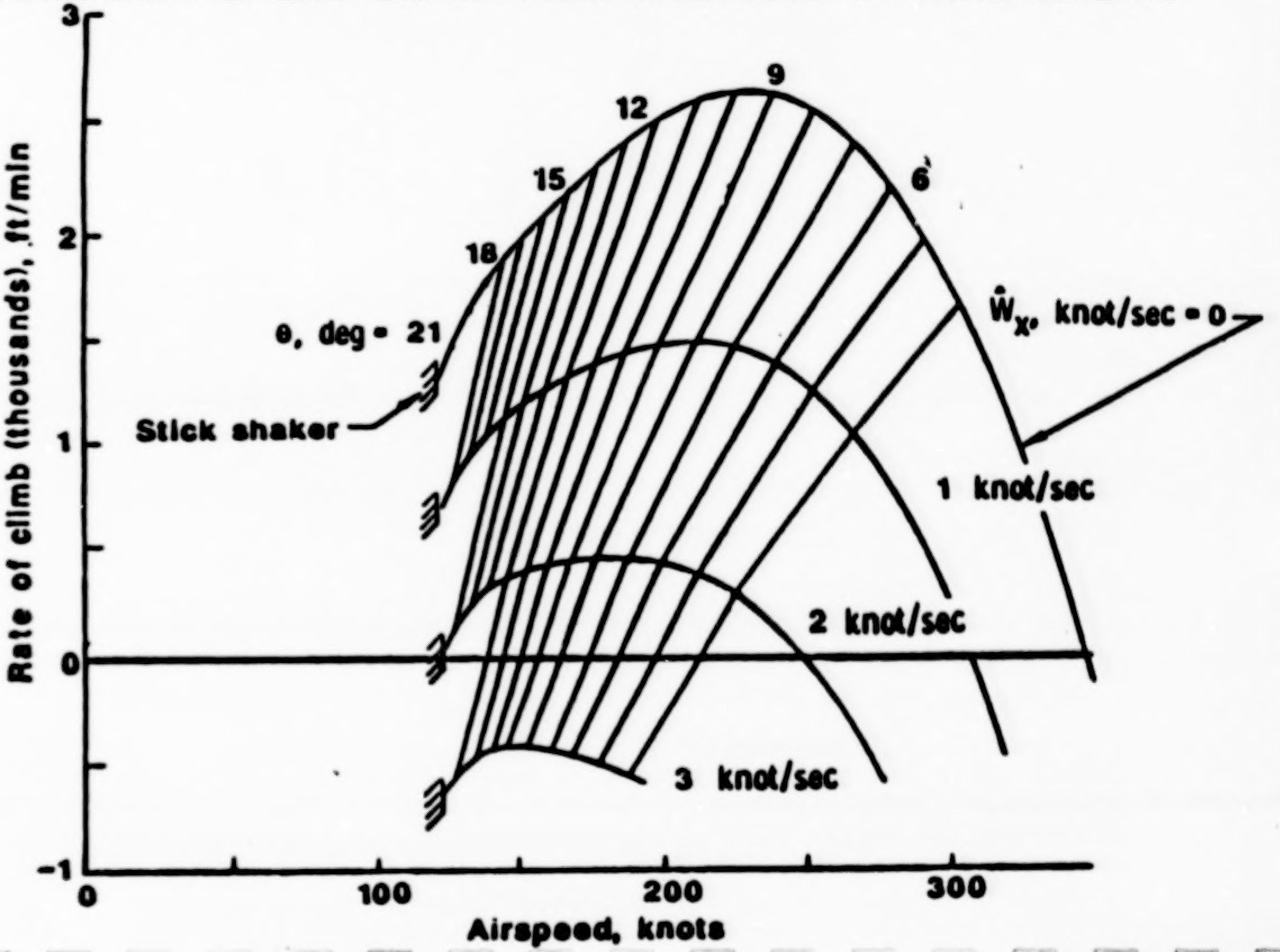
$$\dot{h}_p = \frac{\dot{E}}{W} \cong \left(\frac{T - D}{W}\right) V - \overbrace{\left(\frac{\dot{W}_x}{g} \cos\gamma + \frac{\dot{W}_h}{g} \sin\gamma - \frac{W_h}{V}\right)}^{\text{WIND SHEAR "HIT"}} V$$

O JET TRANSPORTS IN TAKE-OFF CONFIGURATION

$$.1 \leqq \frac{T - D}{W} \leqq .3 \qquad \left|\dot{W}_x\right| = \left|\dot{W}_h\right| \leqq .3\,g \qquad \left|\frac{W_h}{V}\right| \leqq .25$$

Boeing 737–100

CONSTANT SPEED CLIMB PERFORMANCE IN WIND SHEAR



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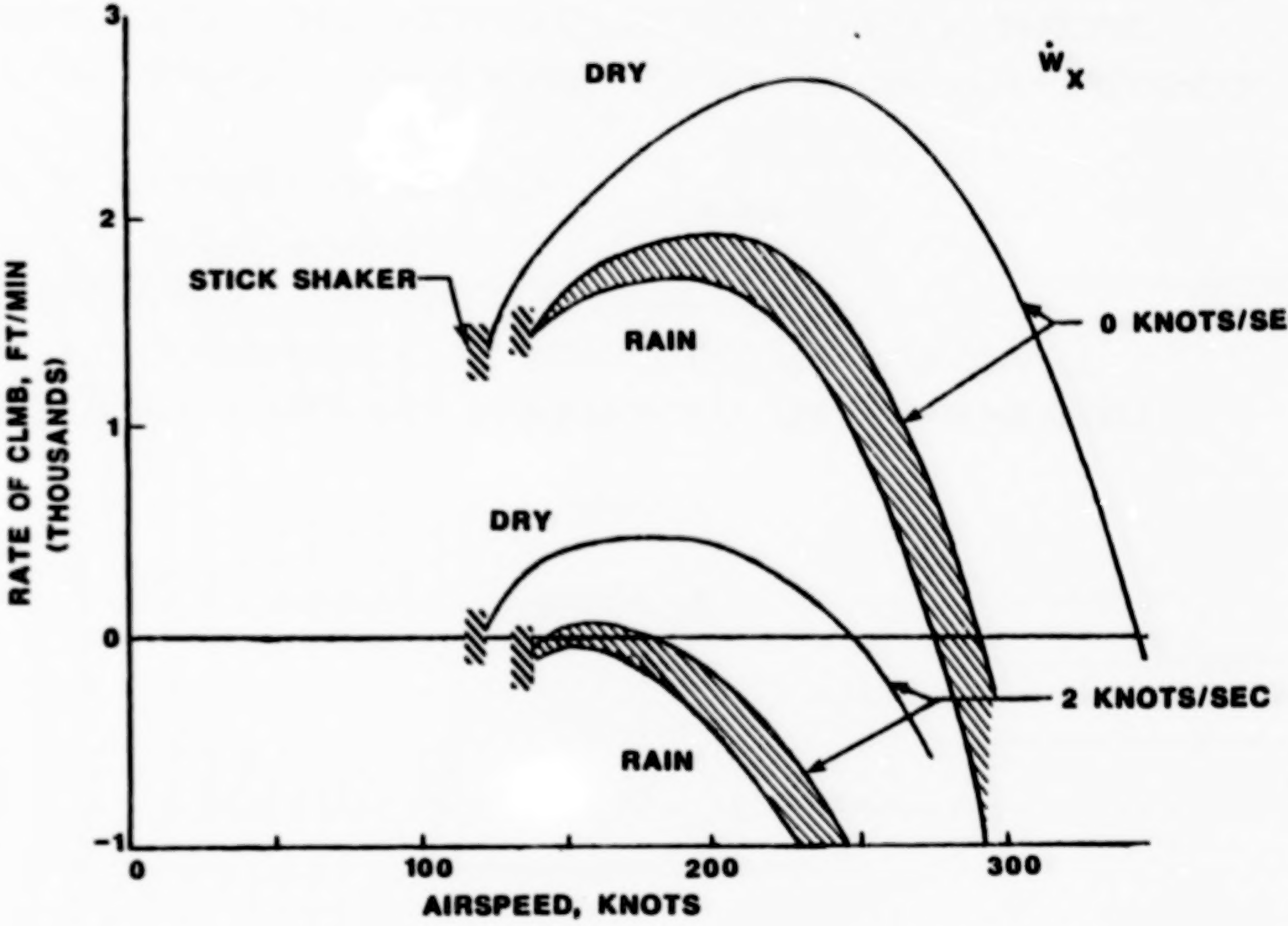
R Bow VPS

CONSTANT SPEED CLIMB PERFORMANCE IN SHEAR AND HEAVY RAIN

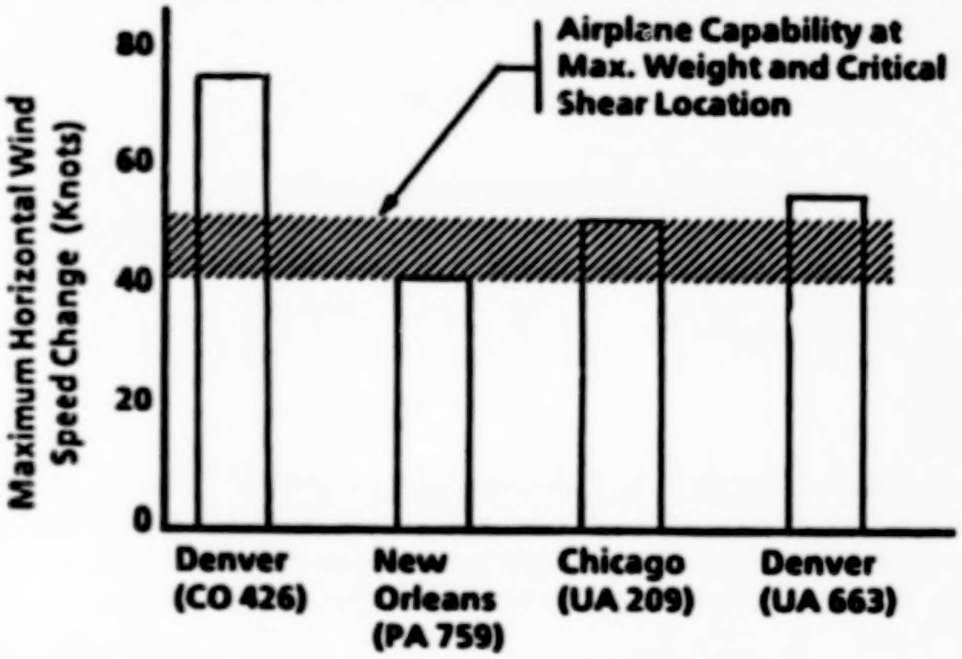
BOEING 737-100

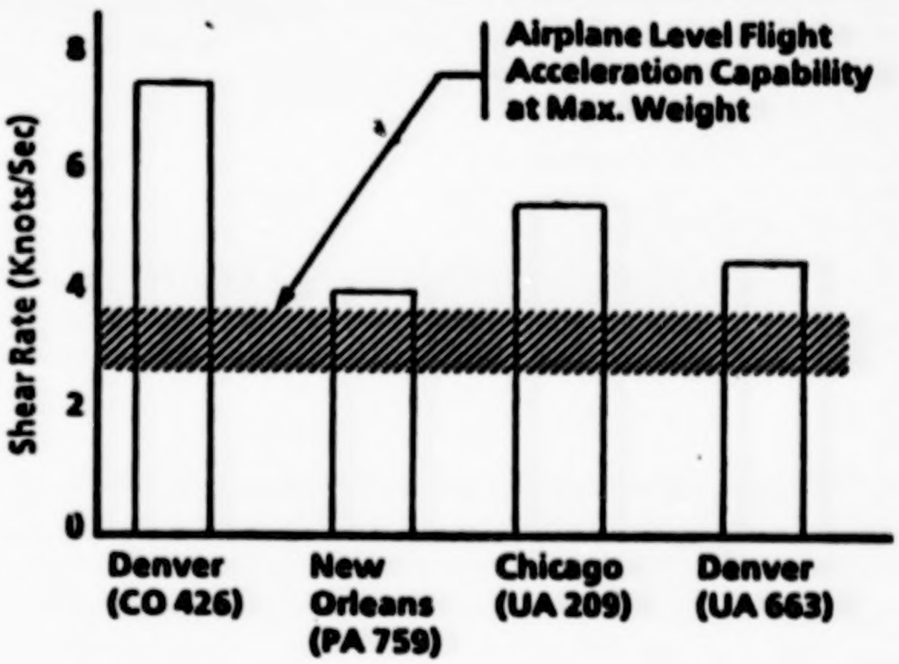


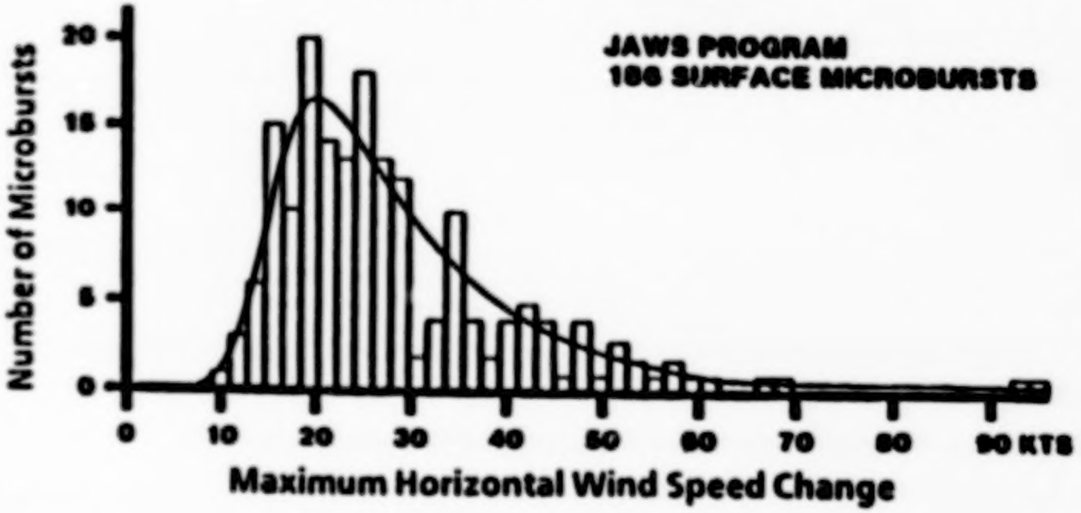
WIND SHEAR "HIT"

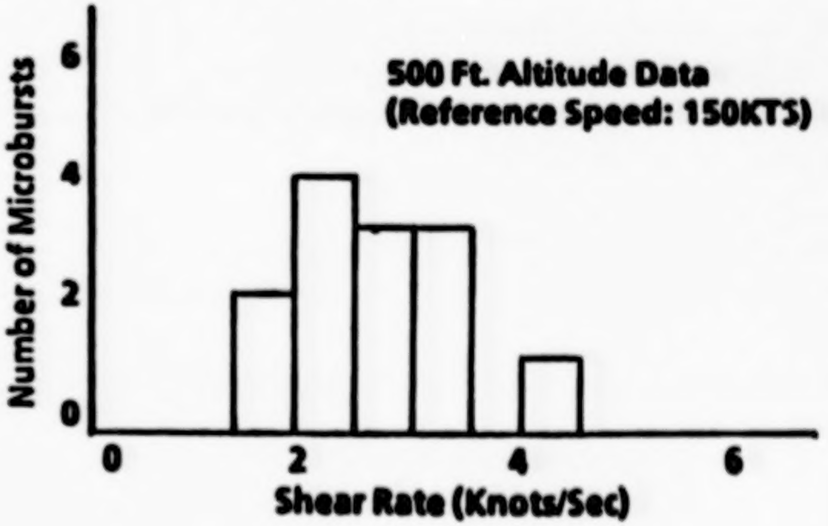
- HAZARD INDEX $F = \frac{\dot{W}_x}{g} - \frac{W_h}{V}$
- ALERT AND WARNING THRESHOLD DETERMINED BY MAX. PERMISSIBLE F IN RELATION TO AIRCRAFT PERFORMANCE CAPABILITY
- F IS A SENSED QUANTITY
- HAZARD INDEX APPLICABLE TO BOTH INSITU—SENSED INFORMATION AND REMOTE—SENSED WIND SHEAR

Accident Windshears Compared to Airplane Capabilities and Measured JAWS Data

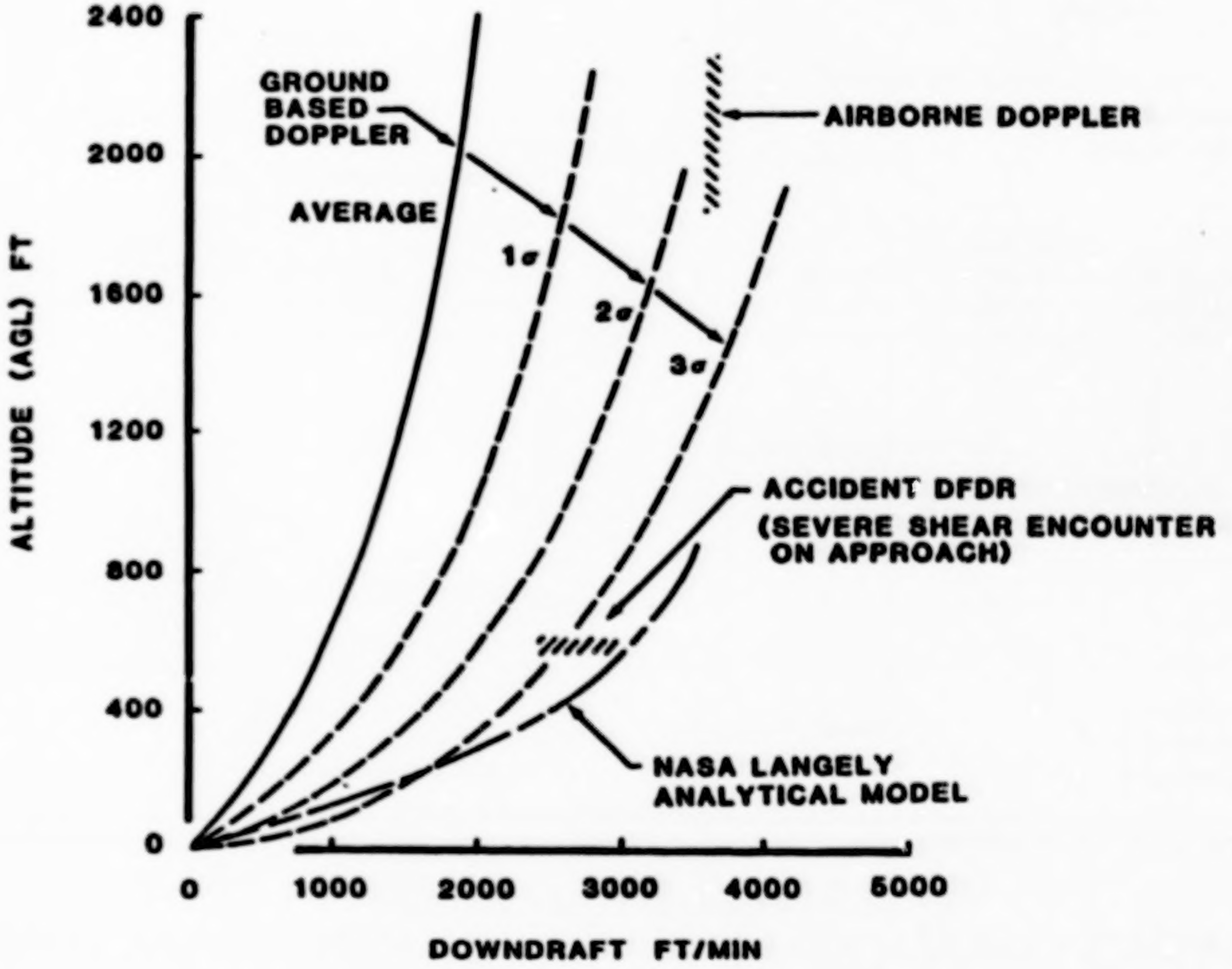






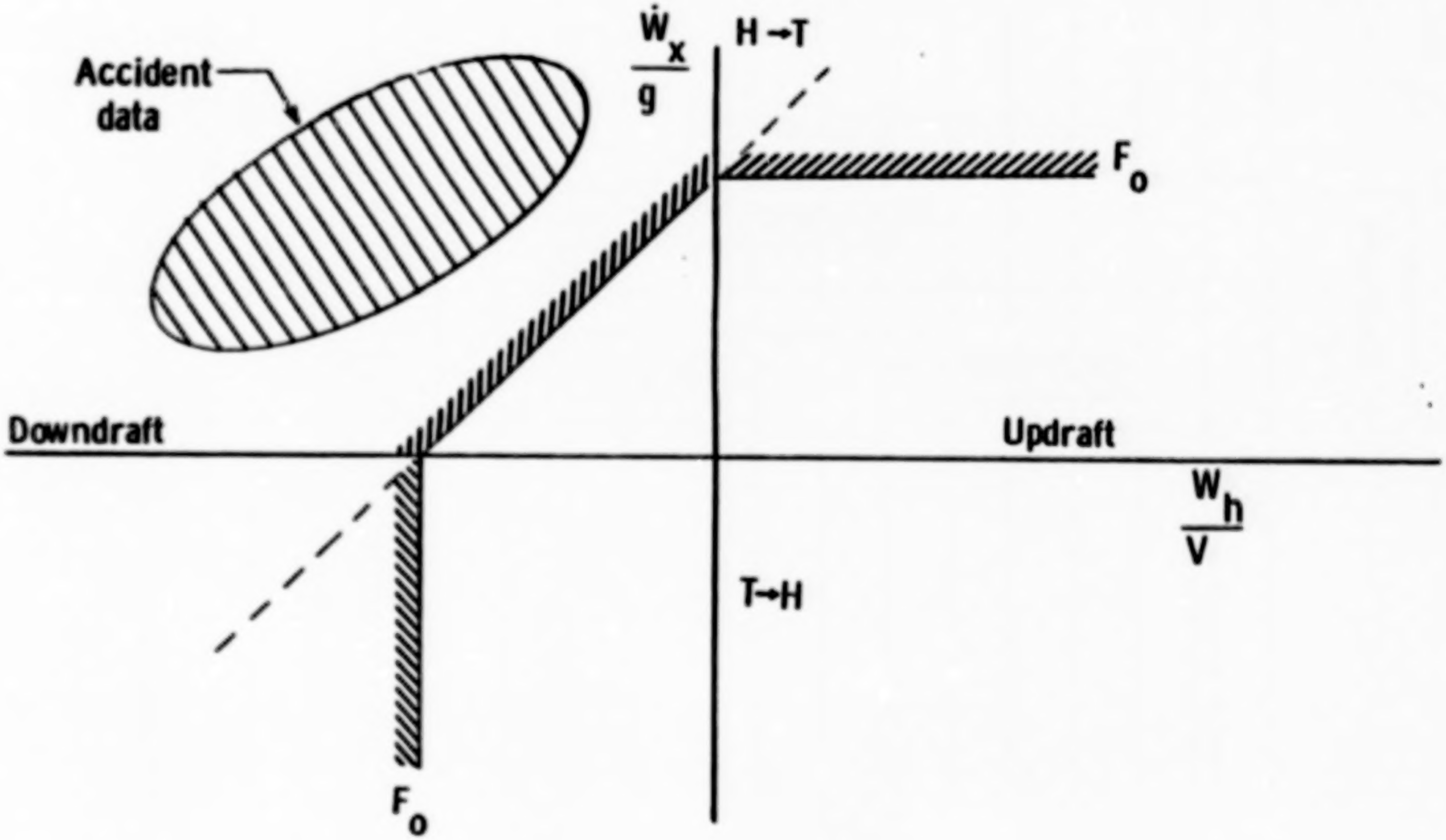


Vertical Wind Effect of Altitude



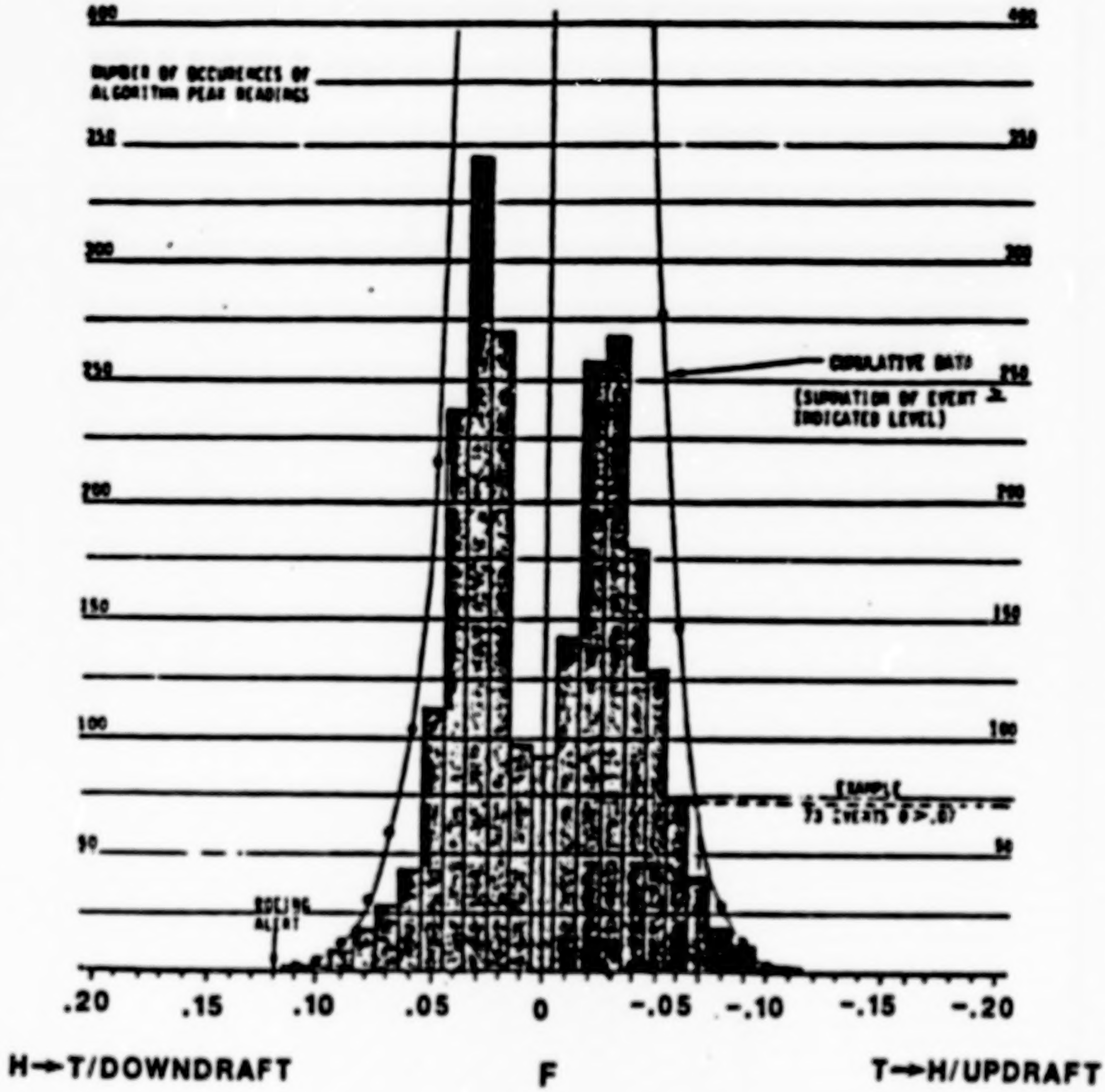
HAZARD INDEX

$$\boxed{\frac{\dot{W}_x}{g} - \frac{W_h}{V} \geq F_o}$$



SOUTHWEST 737-300 IN-SERVICE DATA

TAKEOFF



NO WIND SHEAR EVENTS REPORTED BY PILOTS

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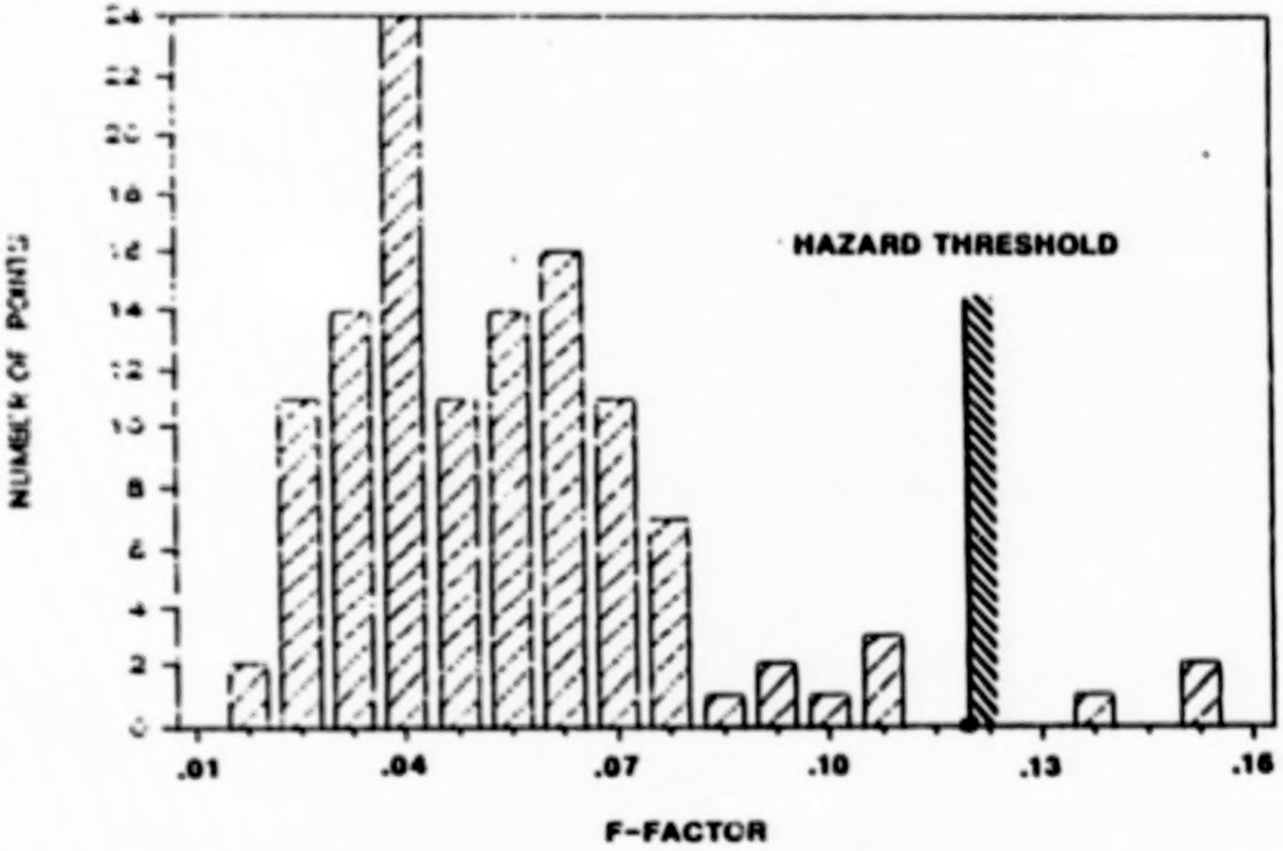
FREQUENCY DISTRIBUTION VS. F-FACTOR

1986 DATA SUMMARY FAA/MIT RADAR



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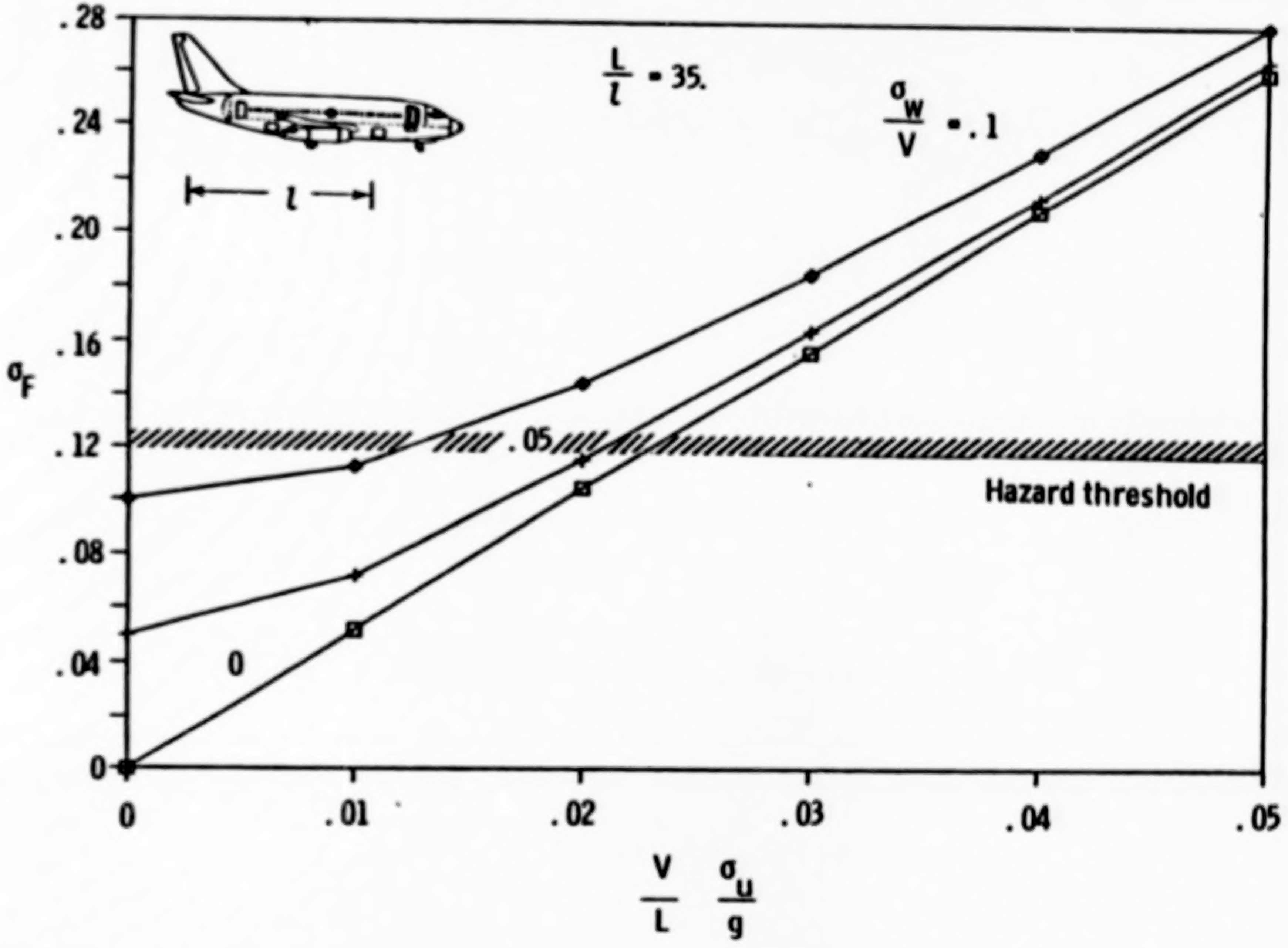
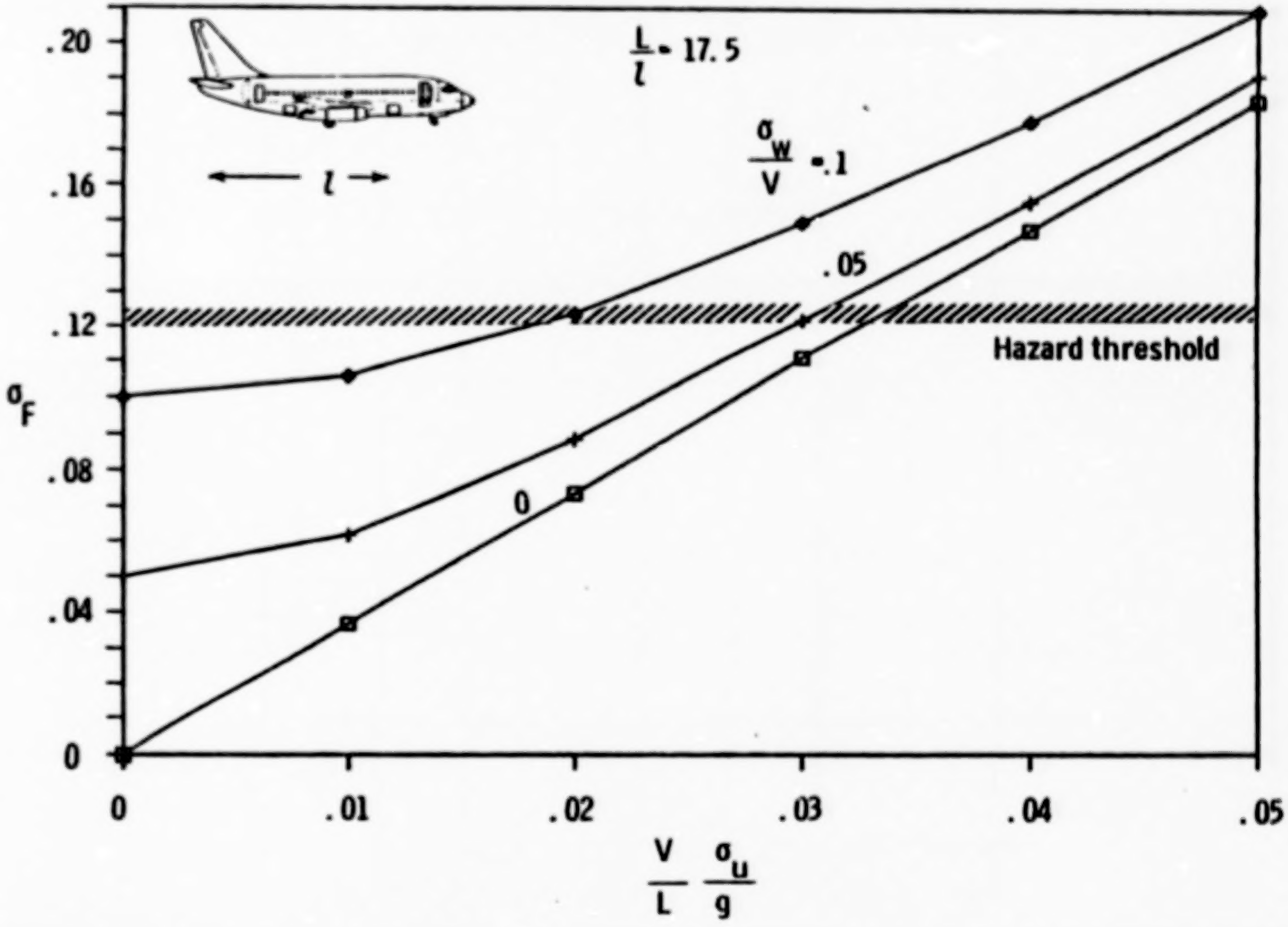
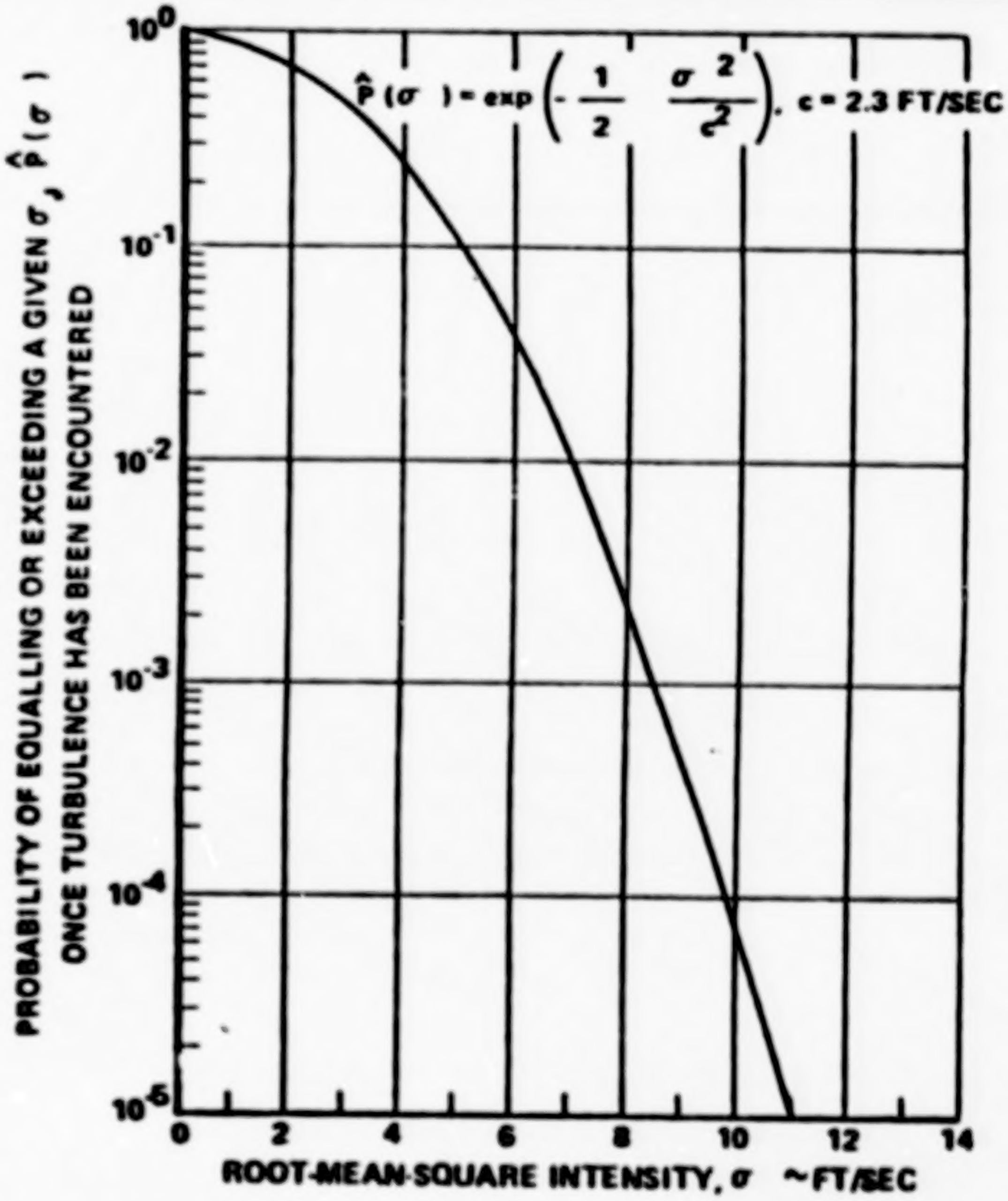
STANDARD DEVIATION OF F-FACTOR DUE TO TURBULENCE



STANDARD DEVIATION OF F-FACTOR DUE TO TURBULENCE

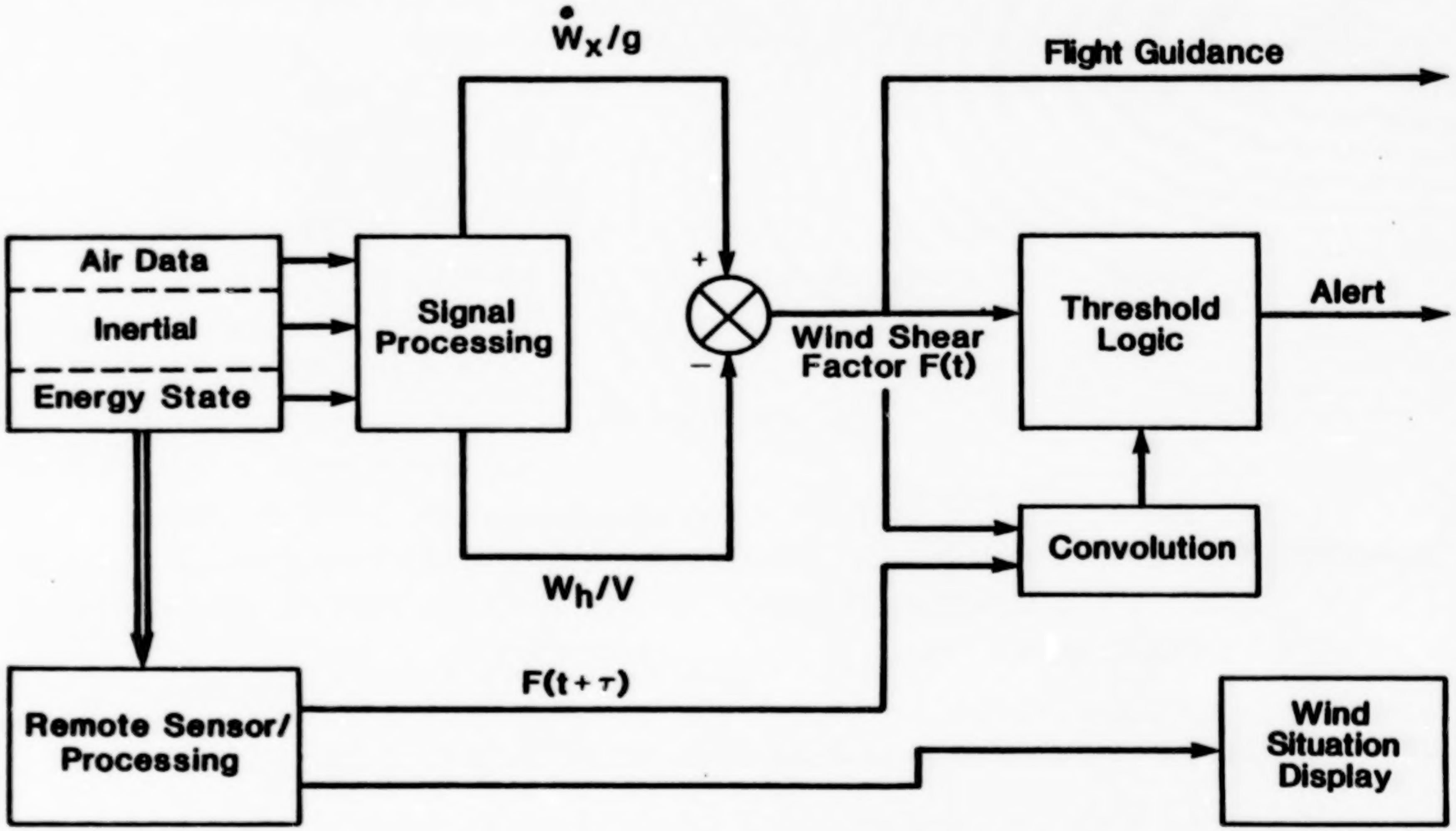


TURBULENCE EXCEEDANCE PROBABILITY



WIND SHEAR ALERT - INSITU DETECTION

SYSTEM CONCEPT



WIND SHEAR ALERT CONSIDERATIONS

O BASED ON WIND SHEAR FACTOR F (TOTAL WIND ENERGY)
O ACTIVATE ALERT IF $F >$ DETECTION THRESHOLD
O DETECTION THRESHOLD A FUNCTION OF AIRCRAFT PERFORMANCE, CONFIGURATION AND POSSIBLY ALTITUDE
O TIMELY ANNUNCIATION
O WARNING LEVEL ALERT? CAUTION?
O AURAL PLUS VISUAL?
O PRIORITY OVER OTHER ALERTS
O NUISANCE ALERTS → INTEGRITY AS GOOD AS GPWS
O HARMONY WITH RECOVERY AND ESCAPE GUIDANCE

o
o
o
o

RECOVERY AND ESCAPE GUIDANCE IN WIND SHEAR

- O INADVERTENT WIND SHEAR ENCOUNTER AFTER LIFT—OFF
- O ALERT VALID
- O MAX. THRUST
- O CLIMB PERFORMANCE $\dfrac{\dot{h} - (R/C)_u}{V} = -\left(\dfrac{\dot{V}}{g} + F\right).$

$$(R/C)_u = \left(\frac{T - D}{W}\right) V \qquad ; \qquad F \approx \frac{\dot{W}_x}{g} - \frac{W_h}{V}$$

WIND SHEAR GUIDANCE LAW

- BASED ON PROPORTIONALITY BETWEEN $\dot{V}/g$ AND F, NAMELY

$$\frac{\dot{V}}{g} = -\lambda F$$

- IMPLICATION $\quad \dfrac{\dot{h} - (R/C)_u}{V} = -(1 - \lambda)F$

- DEMONSTRATES CLIMB RECOVERY IN WIND SHEAR THROUGH ACCELERATION GUIDANCE
  - DETERMINES PITCH COMMAND AS A FUNCTION OF AIRCRAFT STATE VARIABLES AND SHEAR/DOWNDRAFT FACTOR F
  - BEST λ ? (AIRPLANE DEPENDENT)

PRECEDING PAGE BLANK NOT FILMED

INTERPRETATION OF λ

λ - CONTINUUM

- O CONSERVE KINETIC ENERGY
- O CONSTANT AIRSPEED CLIMB
- O ACCELERATE OVER GROUND
- O PITCH DOWNWARD TO ACHIEVE ACCELERATION

USES UP CLIMB CAPABILITY

- O CONSERVE POTENTIAL ENERGY
- O CONSTANT GROUND SPEED CLIMB
- O DECELERATE RELATIVE TO AIR
- O SMOOTH PITCH UPWARD

BENEFICIAL RECOVERY OF CLIMB CAPABILITY

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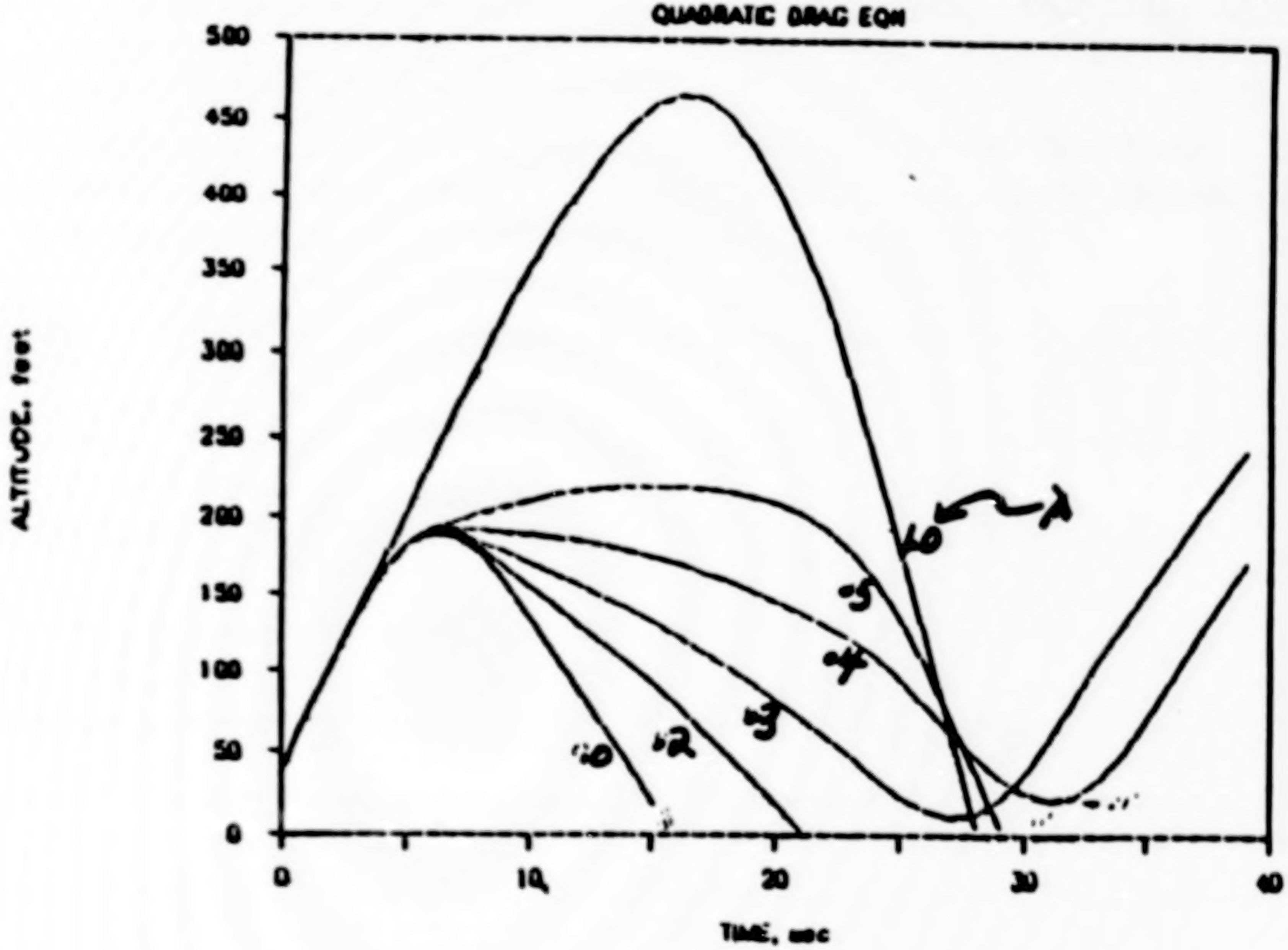
ACCELERATION GUIDANCE [illegible] SWEEPS



NASA FORM 1598 APR 82

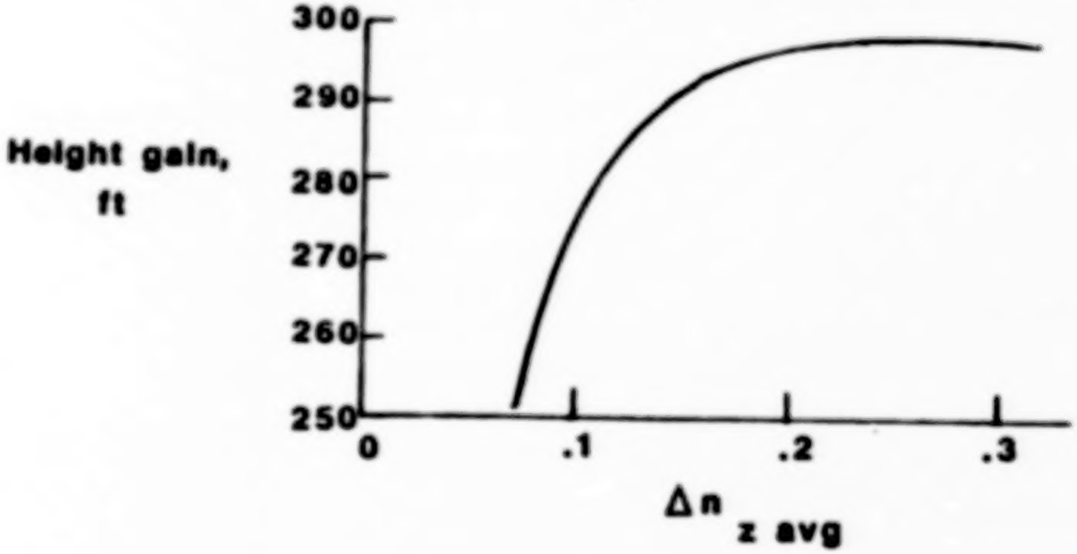
BASIC NOTIONS

- CHASING AIRSPEED $(\lambda = 0)$
  - ENERGY FOOLISH
  - USES UP CLIMB CAPABILITY

- AGGRESSIVE PULL UP $(\lambda = 1)$
  - EXPENSIVE USE OF ENERGY
  - MAY END UP AT STICK SHAKER WITH NOTHING LEFT

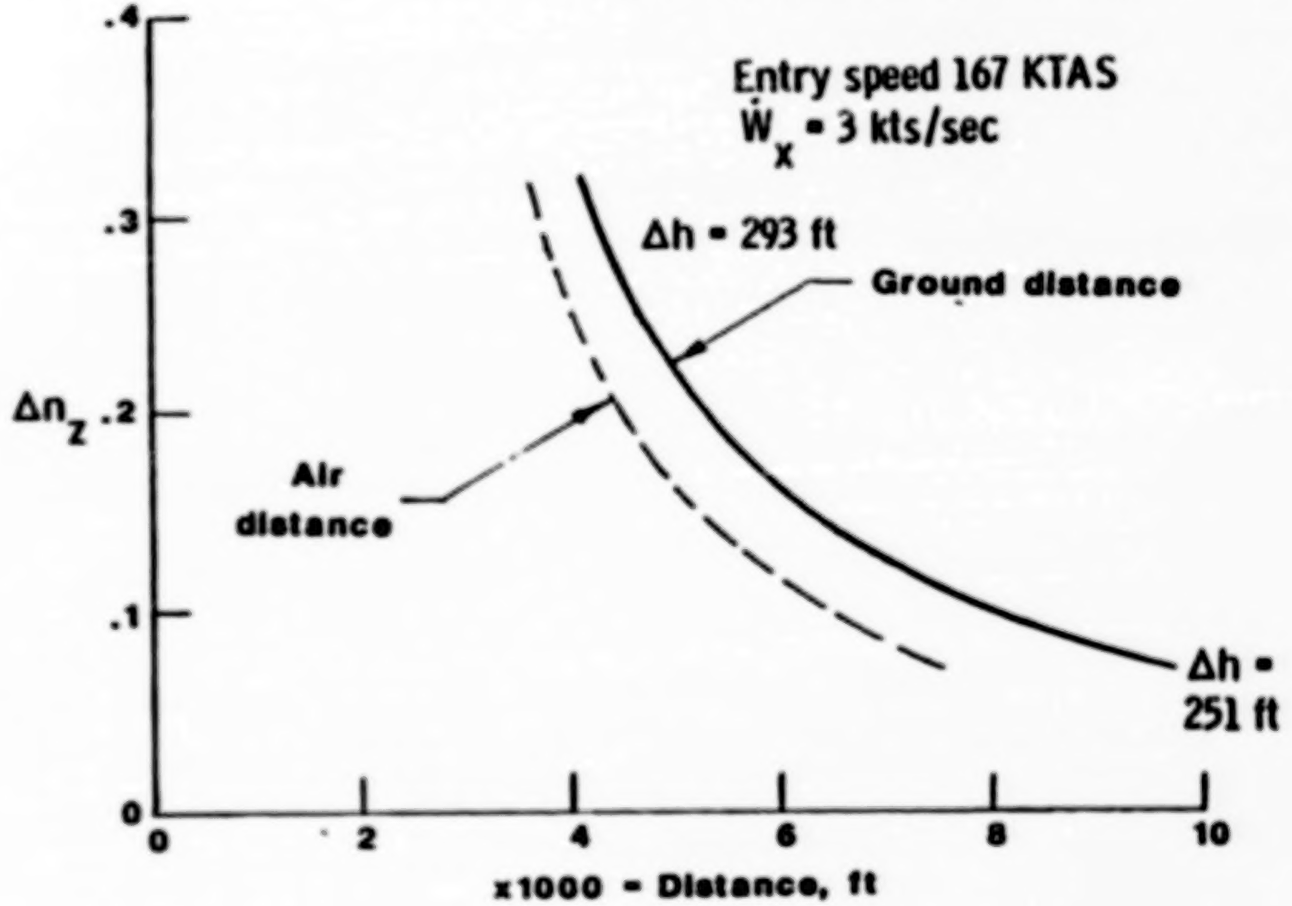
- PITCH COMMAND THROUGH ACCELERATION GUIDANCE $(0 < \lambda < 1)$
  - ENERGY SMART
  - MATCHES CLIMB TO ENERGY AVAILABLE
  - MAY COMMAND LEVEL FLIGHT IN SEVERE WIND SHEAR
  - EXTENDS FLIGHT TIME AND DISTANCE OVER GROUND

BOEING 737–100
EFFECT OF CONTROLLED NORMAL ACCELERATION ON HEIGHT GAINED IN HORIZONTAL SHEAR
$\dot{W}_x$ = 3 KT/SEC

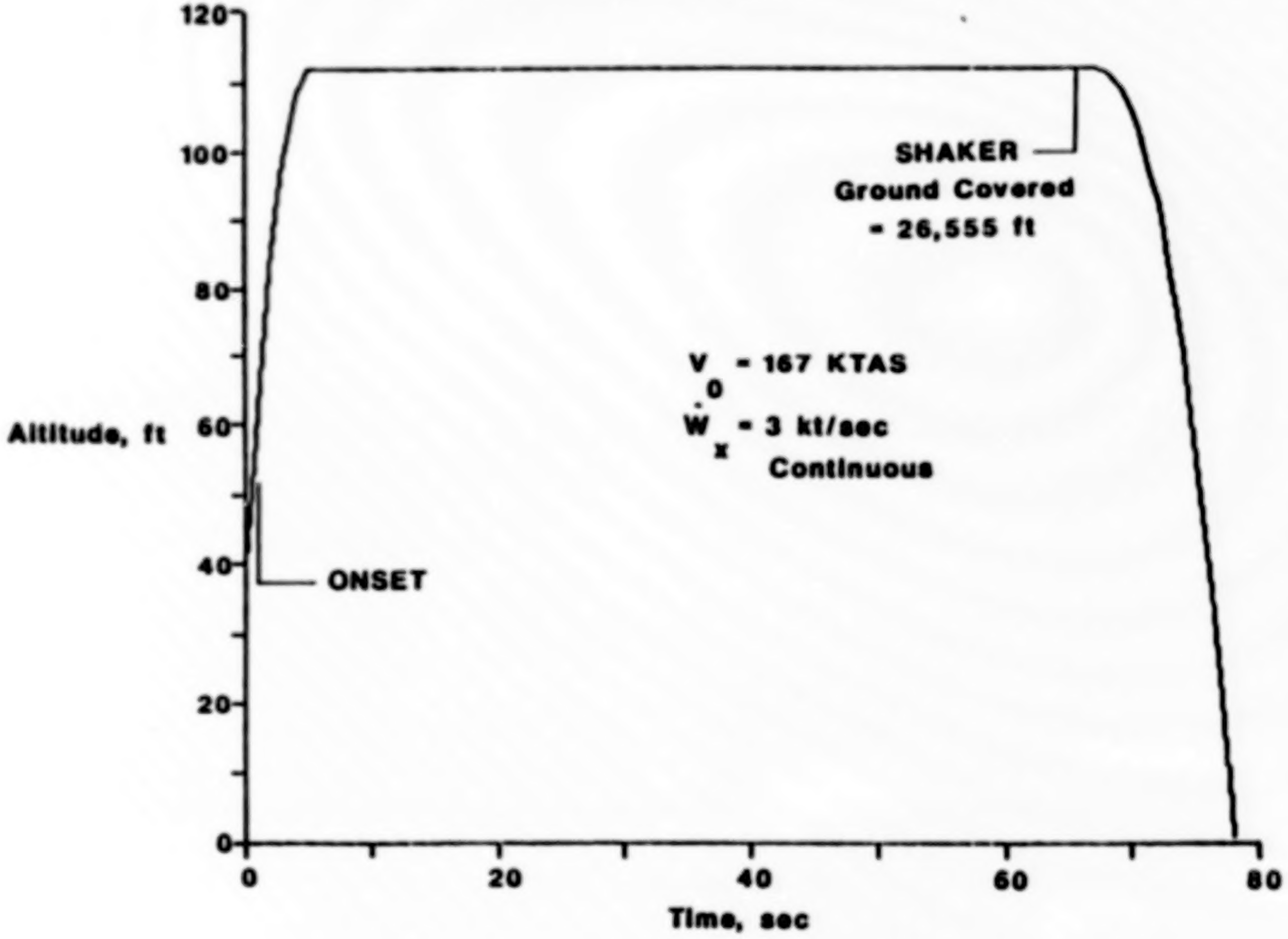


BOEING 737
HORIZONTAL DISTANCE TRAVELLED BETWEEN BURST ONSET AND SHAKER

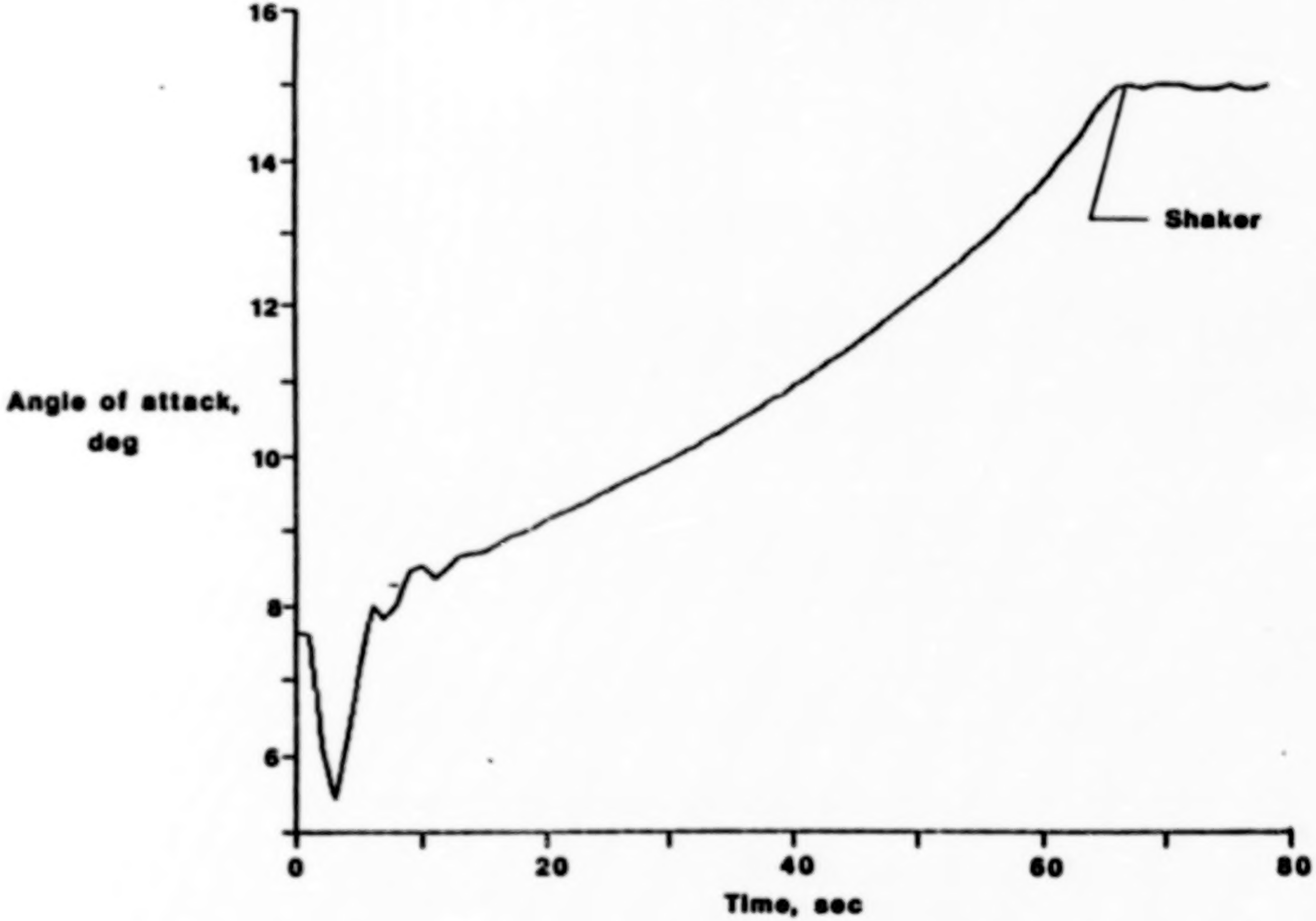
Effect of normal acceleration



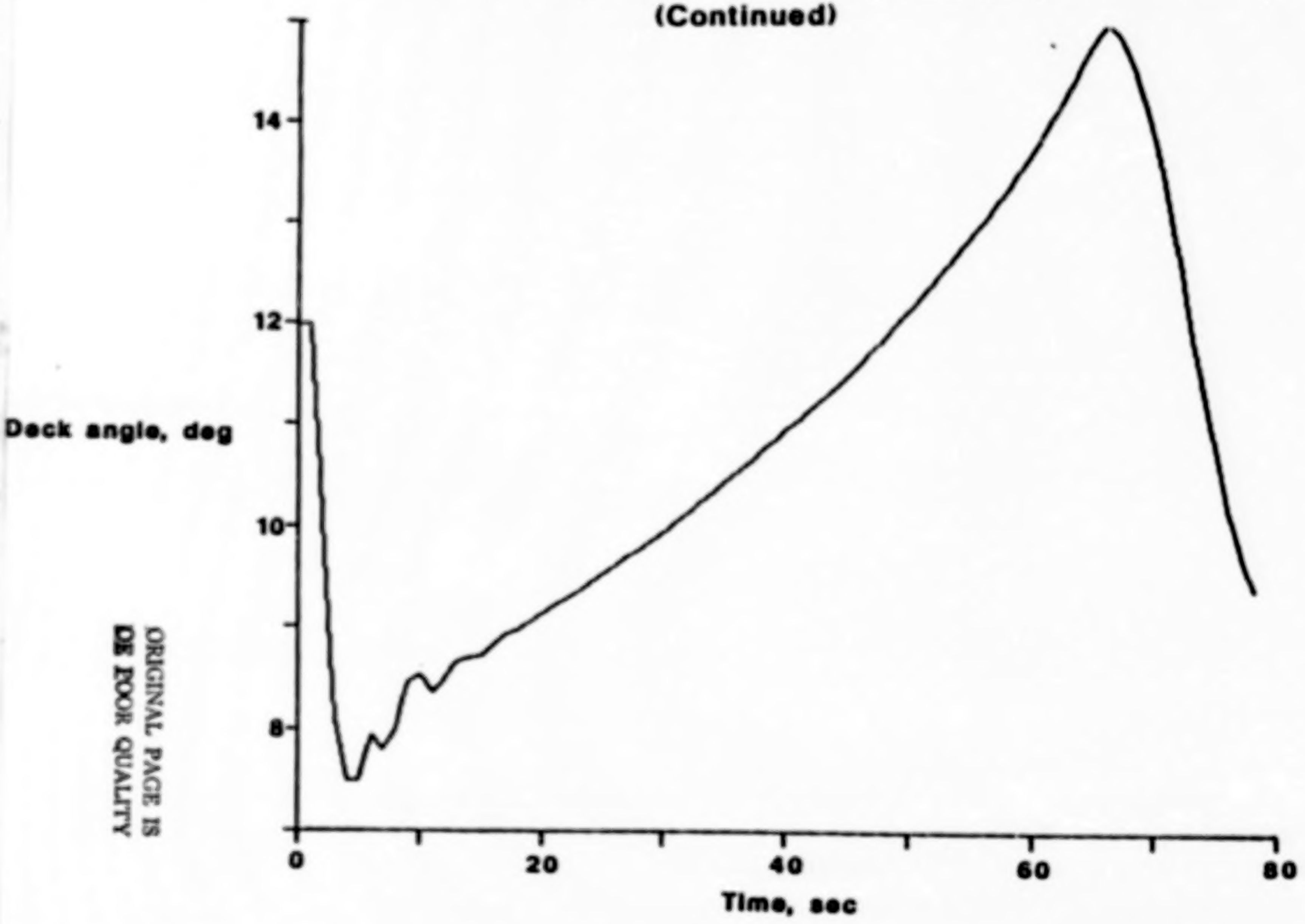
BOEING 737-100
EFFECT OF ZERO-CLIMB-ANGLE HOLD



BOEING 737-100
EFFECT OF ZERO-CLIMB-ANGLE HOLD
(CONTINUED)



BOEING 737–100
EFFECT OF ZERO–CLIMB–ANGLE HOLD
(Continued)



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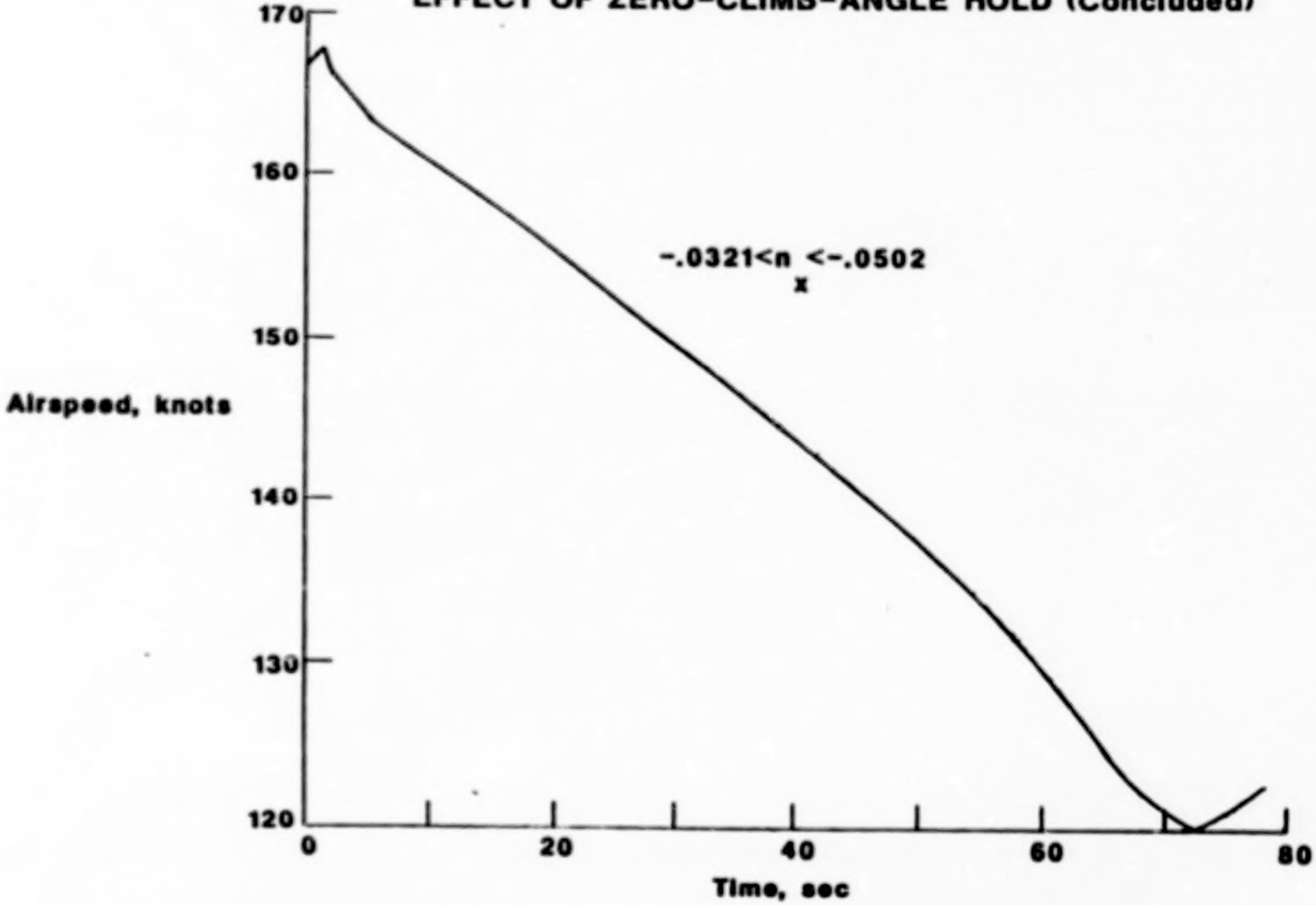
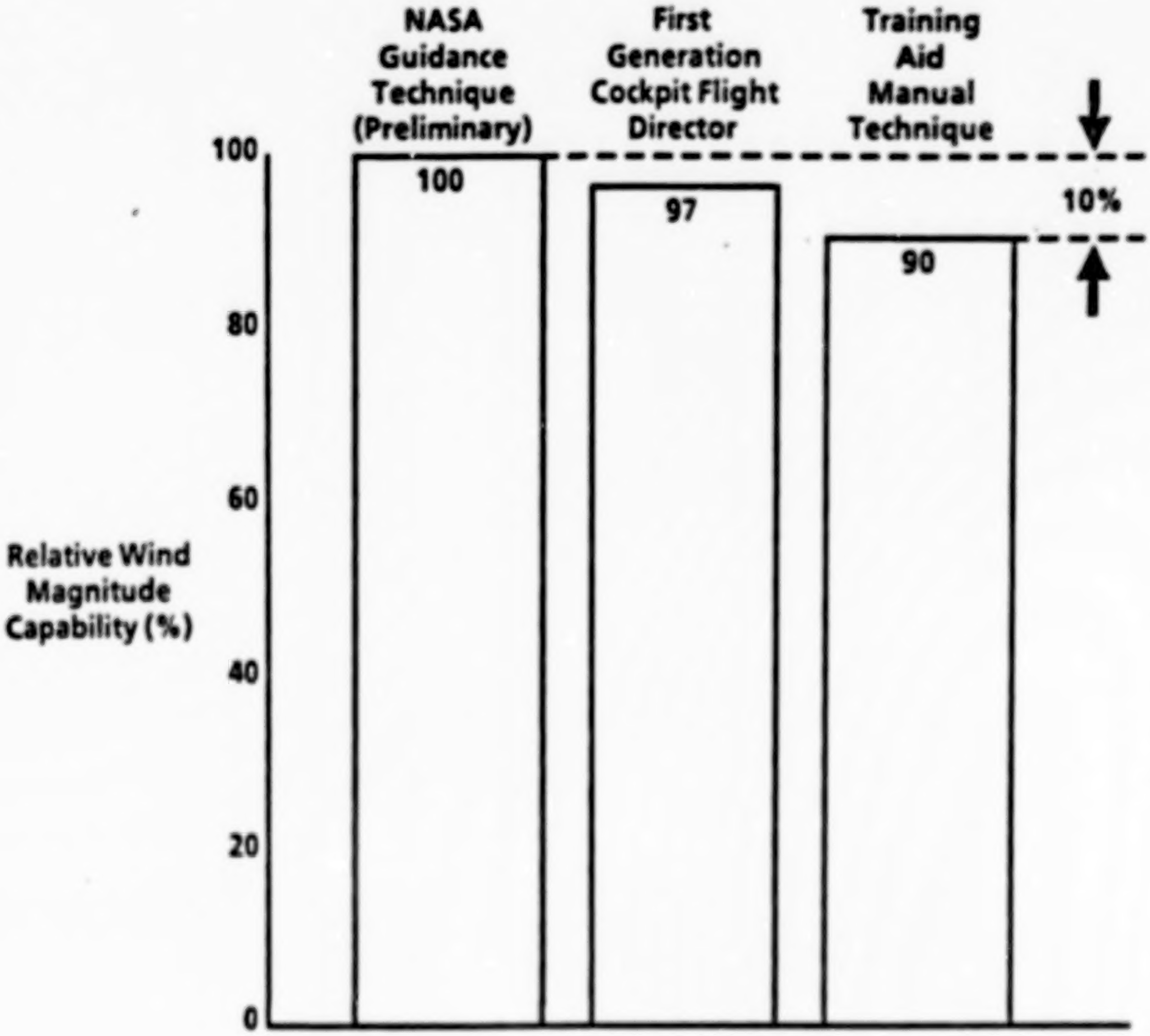
BOEING 737-100
EFFECT OF ZERO-CLIMB-ANGLE HOLD (Concluded)



Windshear Recovery Capability

NOTE:
1. 737-300, 122,000 lb, Flaps 5, CFM56-3-B1, S. L., 100°F.
2. Windshear encounter at 100 ft. following takeoff.
3. Guidance assumes instant recognition. Manual technique recovers after 15 kt. airspeed loss.
4. Horizontal windshear at 5.7 kt/sec.



Windshear Recovery Capability. Recommended Manual Technique vs. Preliminary NASA Guidance Technique and First Generation Cockpit Flight Director Guidance.

FUTURE EFFORTS

- SIMULATOR EVALUATION OF ACCELERATION GUIDANCE CONCEPT
- CONVENTIONAL COCKPIT DISPLAYS/FLIGHT DIRECTOR
- ADVANCED COCKPIT ENVIRONMENT
  - FLIGHT PATH SITUATION DISPLAYS
  - IMPROVED CONTROL CAPABILITY

AIRBORNE DOPPLER TECHNOLOGY FOR WIND SHEAR DETECTION

E. M. Bracalente
NASA/LaRC

AIRBORNE DOPPLER RADAR TECHNOLOGY FOR WIND SHEAR DECTECTION

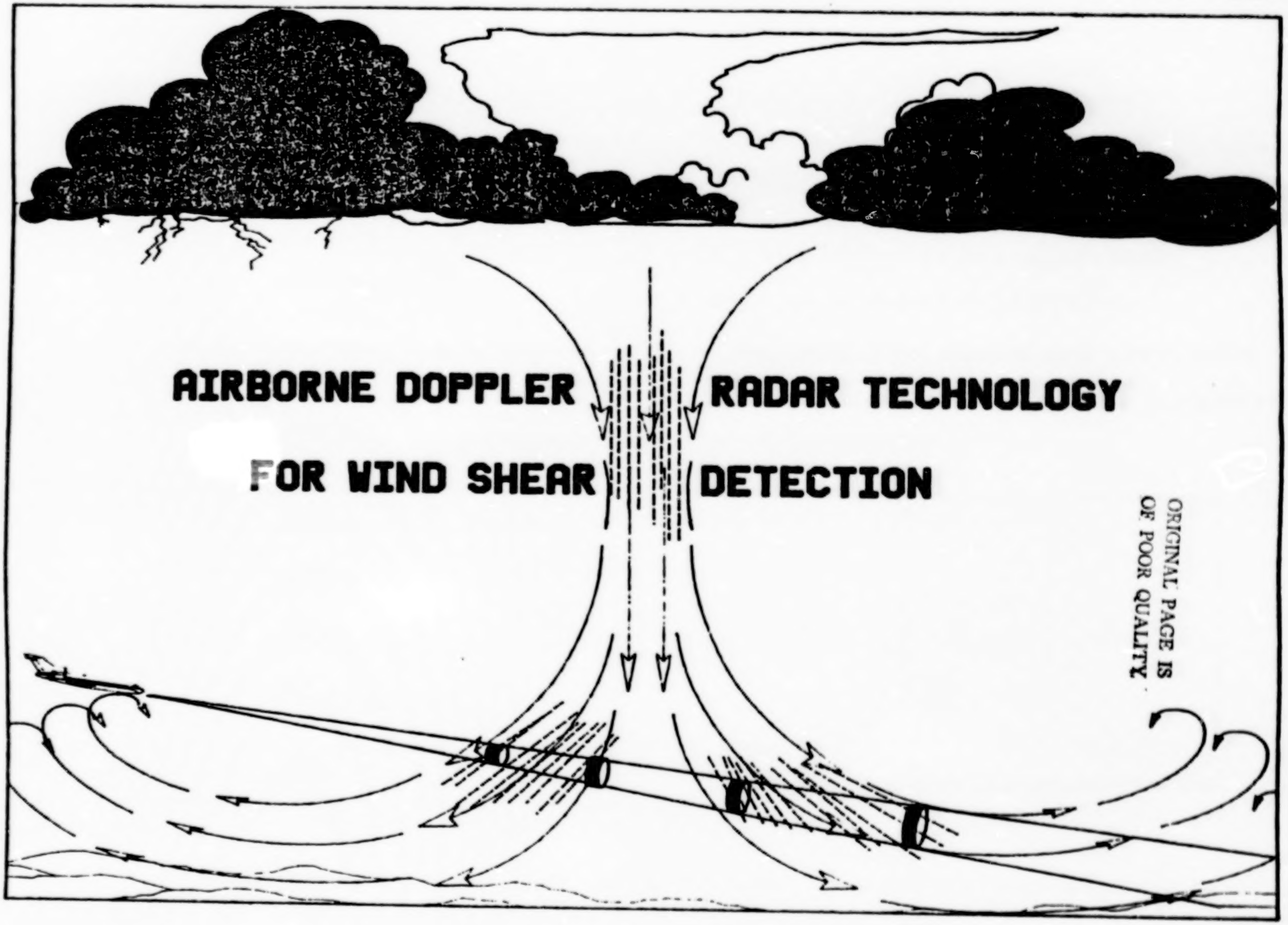
PRESENTED AT:

INDUSTRY REVIEW OF FORWARD LOOKING SENSOR TECHNOLOGY
FOR DETECTION OF WIND SHEAR

LANGLEY RESEARCH CENTER
FEBRUARY 24-25,1987

BY:

E.M. BRACALENTE



AIRBORNE DOPPLER RADAR TECHNOLOGY FOR WIND SHEAR DETECTION

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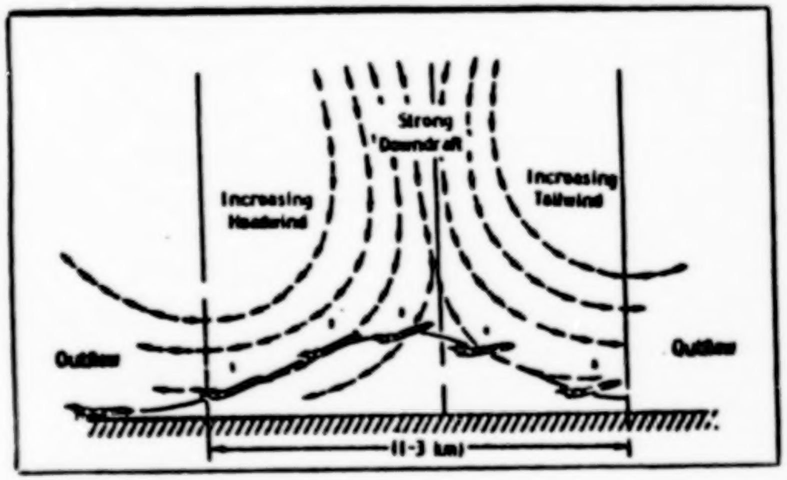
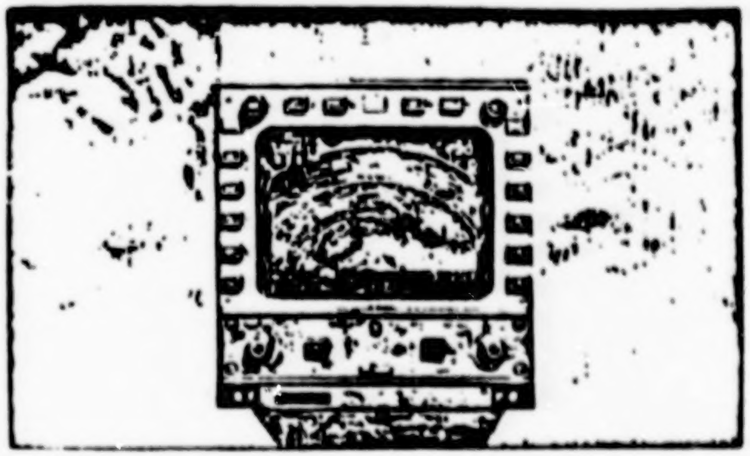
THE WIND SHEAR PROBLEM



- INTENSE,LOCALIZED, SHORT DURATION WEATHER EVENT
- UP TO 100 KNOT ΔV OVER 1-3 KM AT ALTITUDE 1000 FT.
- NEED ADVANCED WARNING - GROUND BASED RADARS,LIDARS,ETC.
- AIRBORNE SENSOR HIGHLY DESIRABLE - RADAR IS NATURAL CHOICE

CURRENT RADAR STATUS AND LIMITATIONS



- RAINFALL REFLECTIVITY AND STANDARD DEVIATION OF TURBULENT VELOCITIES
- NO WIND SHEAR CAPABILITIES

__CHIEF OBSTACLES FOR WIND SHEAR PROBLEM__ :

- ADEQUATE VERTICAL RESOLUTION
- SIGNATURE EXTRACTION AND RECOGNITION
- GROUND CLUTTER SUPPRESSION

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OBJECTIVES

- QUANTIFY PHYSICAL INFLUENCES AND REQUIRED PERFORMANCE BOUNDS FOR USEFUL AIRBORNE DOPPLER RADAR DETECTION OF LOW ALTITUDE WIND SHEAR
- DEVELOP ANALYSIS TOOLS WHICH CAN PROVIDE A BASIS FOR THE EVALUATION AND ANALYSIS OF PROTOTYPE AIRBORNE RADAR DESIGNS THAT CAN LEAD TO EVENTUAL CERTIFICATION
- DESIGN/PROCURE APPROPRIATE EXPERIMENTAL HARDWARE AND STRUCTURE AN EXPERIMENTAL FLIGHT PROGRAM WITH WIDE GOVERNMENT/INDUSTRY SUPPORT TO EVALUATE AND VERIFY AIRBORNE DETECTION AND MEASUREMENT TECHNIQUES

TECHNICAL APPROACH

- Develop realistic computer simulation model of Micro–Burst/Doppler Radar system.
    - –Incorporate μ–Burst wind fields & realistic ground clutter data.
    - –Incorporate various Radar characteristics.
    - –Incorporate signal processing and signature recognition techniques.
    - –Provide various signal and performance analysis capabilities.
- Collect real moving ground clutter data.
    - –Synthetic Aperture Radar (SAR).
    - –Research Scatterometer.
    - –Flight Data.
- Develop and Analyze prototype Doppler Radar designs which can detect low altitude Wind Shear and overcome the limitations of
    - –Moving ground clutter.
    - –Spatial resolution.
    - –Signature Recognition.
- Determine requirements for Doppler Radar design(s) which may be suitable for Wind Shear detection.
    - –Operating Freq.: Ant. Design: XMIT/Rec. Design. –Range, Velocity, & Angular Scan (Az & El) Req.
    - –Update/Sampling rate:
    - –PRF, Pulse period.
    - –Measurement Resolution/Accuracy.
    - –Detection thresholds
    - –Signal processing techniques.
    - –A/C velocity vector information.
    - –Antenna pointing control.
- Flight test prototype techniques.
- Continuing workshops to share results with industry.

PRELIMINARY RANGE OF TRADE-OFF DESIGN PARAMETERS

- OPERATING FREQUENCY --------- X TO KU BAND (PRIMARILY AROUND 9GHz)
- OPERATING RANGE-------------- MAX. GROUND RANGE: 10–15 KM FROM TOUCHDOWN ALTITUDE: 0–1.0KM
- CELL RESOLUTION -------------- 200–500 m
- ANTENNA BEAMWIDTH ---------- 2.5°–4.0°
- DEPRESSION ANGLE ------------- 0° TO –3° LANDING, 0 TO 3 TAKEOFF
- ANGULAR SCAN RANGE ---------- ±10°–20° AZ, TBD IN ELEV.
- DETECTION THRESHOLD--------- 0–10dBZ
- MAX. RADIAL RAIN VELOCITY--- ±30–40 m/s
- VELOCITY RESOLUTION ---------- 1–2 m/s

MAJOR TASK THROUGH FY'87 AND FY'88

- Clutter modeling and analysis.
  - Develop clutter map formulation for radar simulation.
  - Obtain SAR backscatter data from ERIM, incorp. into clutter map.
  - Analyze SAR backscatter data.

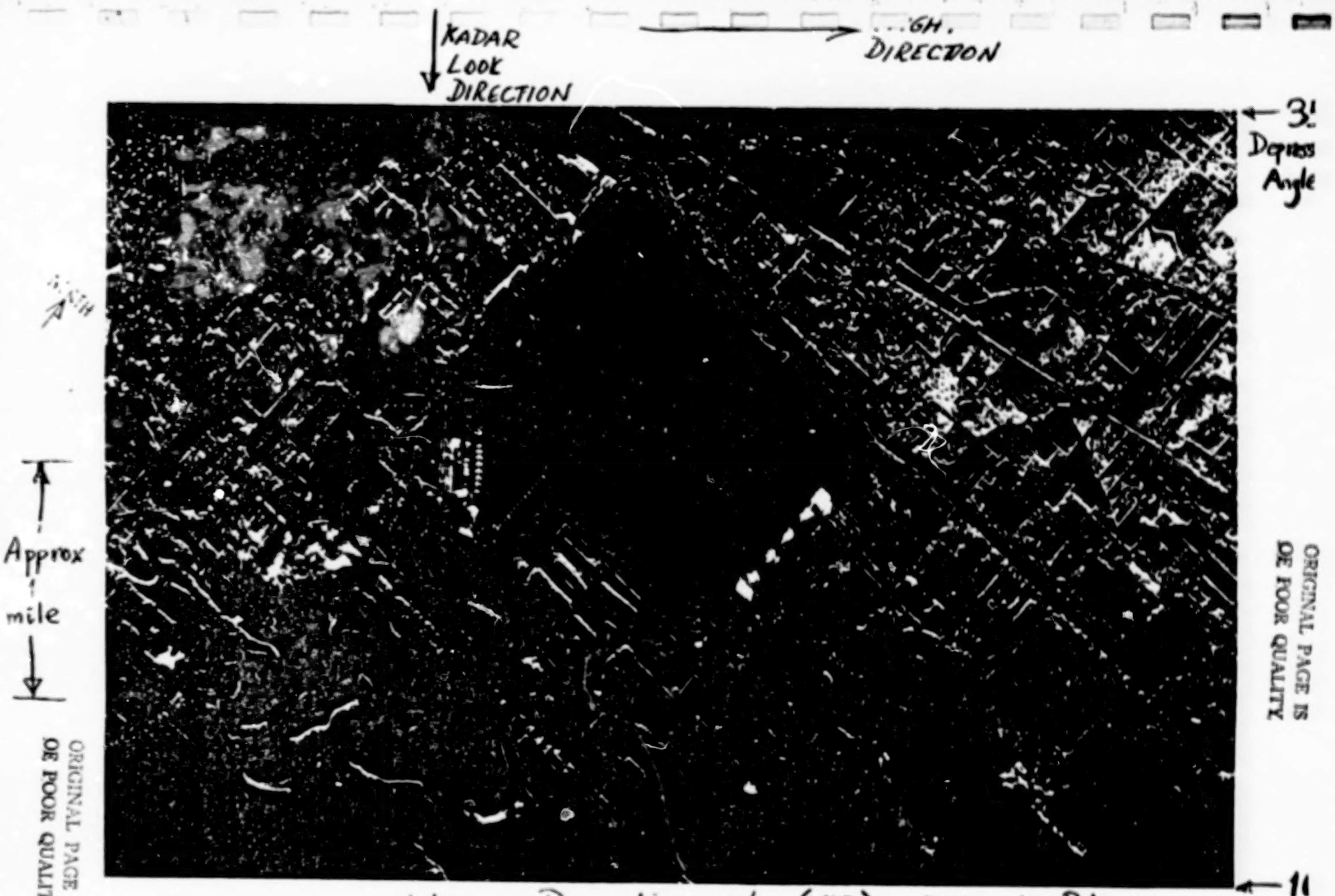
- Atmospheric/Radar computer simulation development
  - Expand present simulation.
  - Continue analytical studies of Doppler spectra from μ-Burst/Rain wind fields.
  - Examine and analyze time domain signal outputs.
  - Make results available to industry.
  - Analyze candidate radar signal processing and design techniques.
  - Develop a candidate set of radar design requirements.

- Flight Radar Scatterometer
  - Analyze and determine scatterometer design requirements and alternative implementation approaches.
  - Evaluate critical subsystems, such as phase noise and speed in freq. synthesizers, T/R Leakage, power amplifiers, etc.
  - Establish data rates and volume: Record/Playback system design.
  - Review industry airborne doppler radar designs for suitability as a flight scatterometer.

STATUS

- Preliminary Radar Simulation Program developed.
  - –Incorporates sample μ–Burst windfields.
  - –Simulates various radar characteristics.
  - –Full antenna pattern integration
  - –Preliminary clutter modeling.
  - –FFT processing for computing doppler spectrum.
  - –Computes various radar parameters.
- Various other doppler radar and signal/clutter spectrum analysis programs have been written.
- Preliminary doppler radar design analyses have been performed.
  - –Including performance trade–offs.
  - –Signal and clutter doppler spectrum analysis.
- Preliminary design analysis of experimental radar scatterometer requirements has been done, identifying critical subsystem designs requiring further study.
- Initial design of clutter map formulation using estimated backscatter levels.
  - –Digitized backscatter map from SAR image of Willow Run Airport has been made and incorporated in simulation program.
- Study contract award to ERIM for procurement of clutter data.
  - –Survey inventory of the existing SAR data base which may fit the wind shear radar conditions.
  - –Analyze and process SAR data.
  - –Provide digital images and tapes of backscatter data suitably formated for incorporation in our clutter map.
  - –Conduct future ground and/or flight clutter data collection experiments if appropriate.

- SBIR contract to Sierra Nevada Corporation (SNC)
  - –Measure wind velocity gradient between range gate cells.
    - –Doppler processed phase reference of each range gate cell are compared to derive differential velocity.
    - –Lower PRF (1/10) is needed then for absolute velocity measurement.
  - –Verify concept via analysis of existing radar windshear data.
    - –Use MIT Lincoln lab data.
  - –Record additional X–band doppler data during on–going SNC/Navy SPN–42 ground test program.
    - –Incorporate Quad. phase detector––record output for analysis.
  - –Phase II effort involves fabrication of a processor for field testing.
- Northeastern University grant has been initiated.
  - –Develop analytical doppler radar clutter simulation program for airport clutter enviroment.
  - –Conduct clutter analysis during landing and take–off, using simulation program, for a number of airports.



Willow Run Airport (YIP)
SAR Image

Dark = Low Return
Light = High Return

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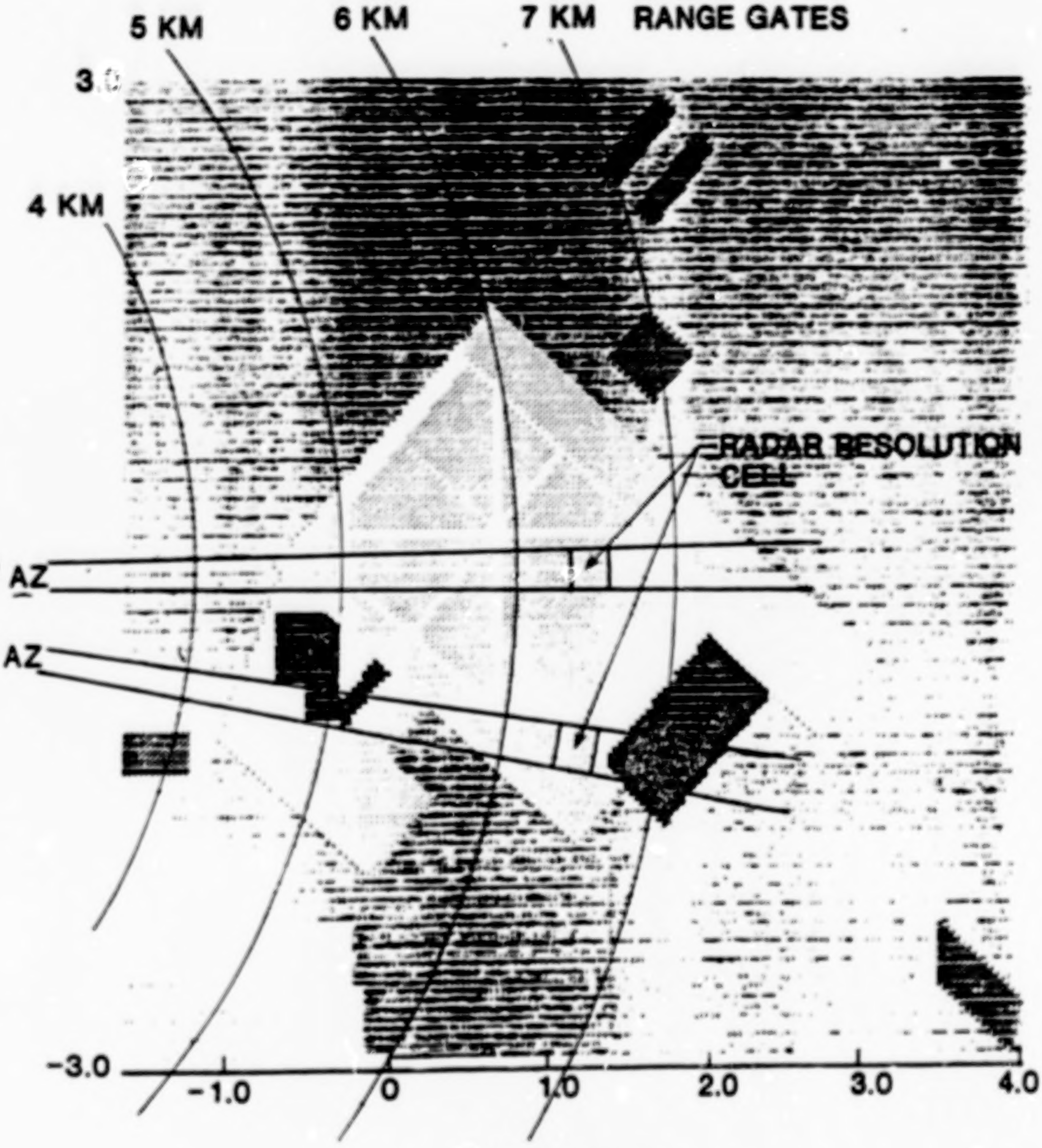
WILLOW RUN (YIP) CLUTTER MODEL #1



KILOMETERS

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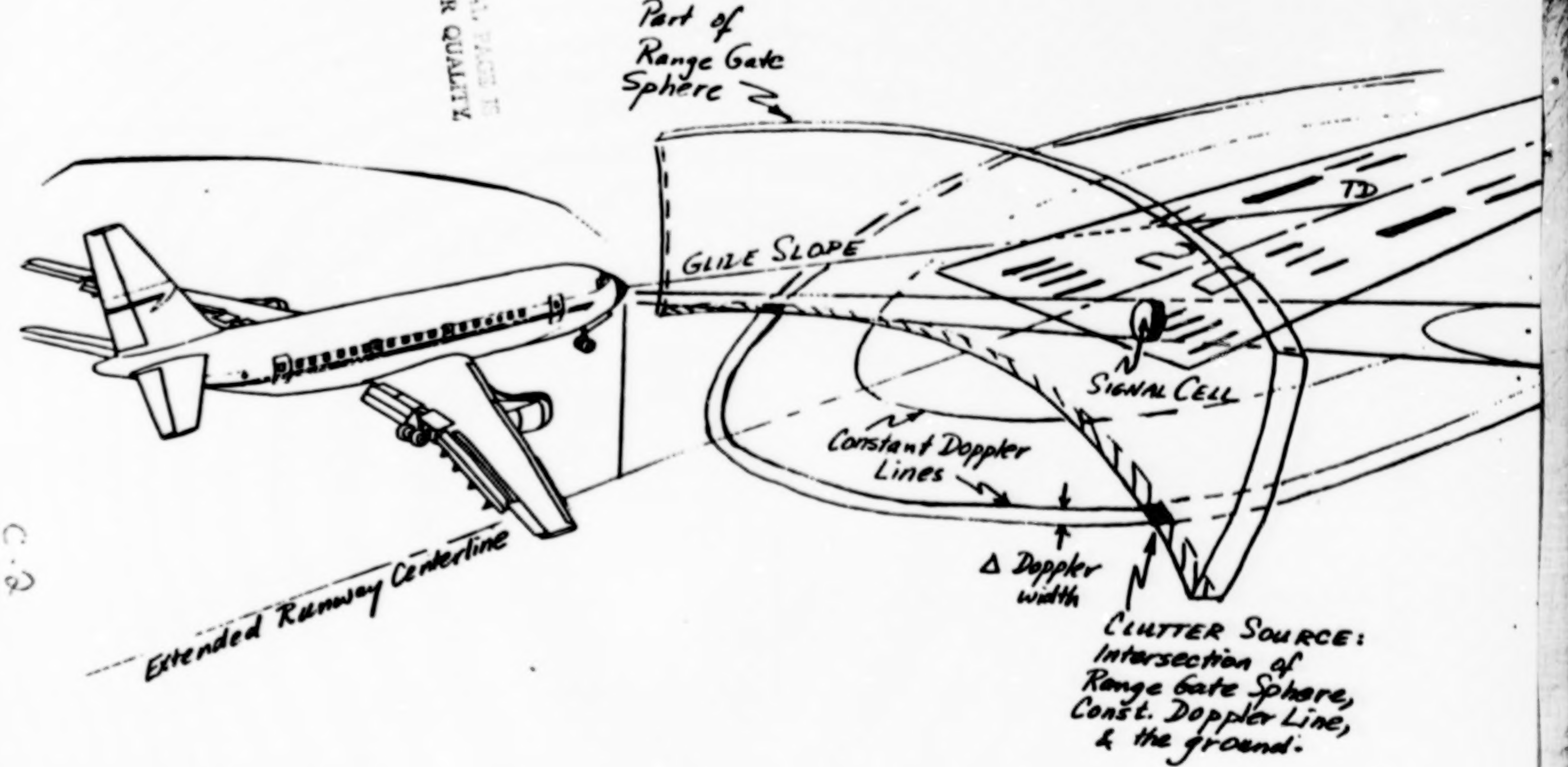
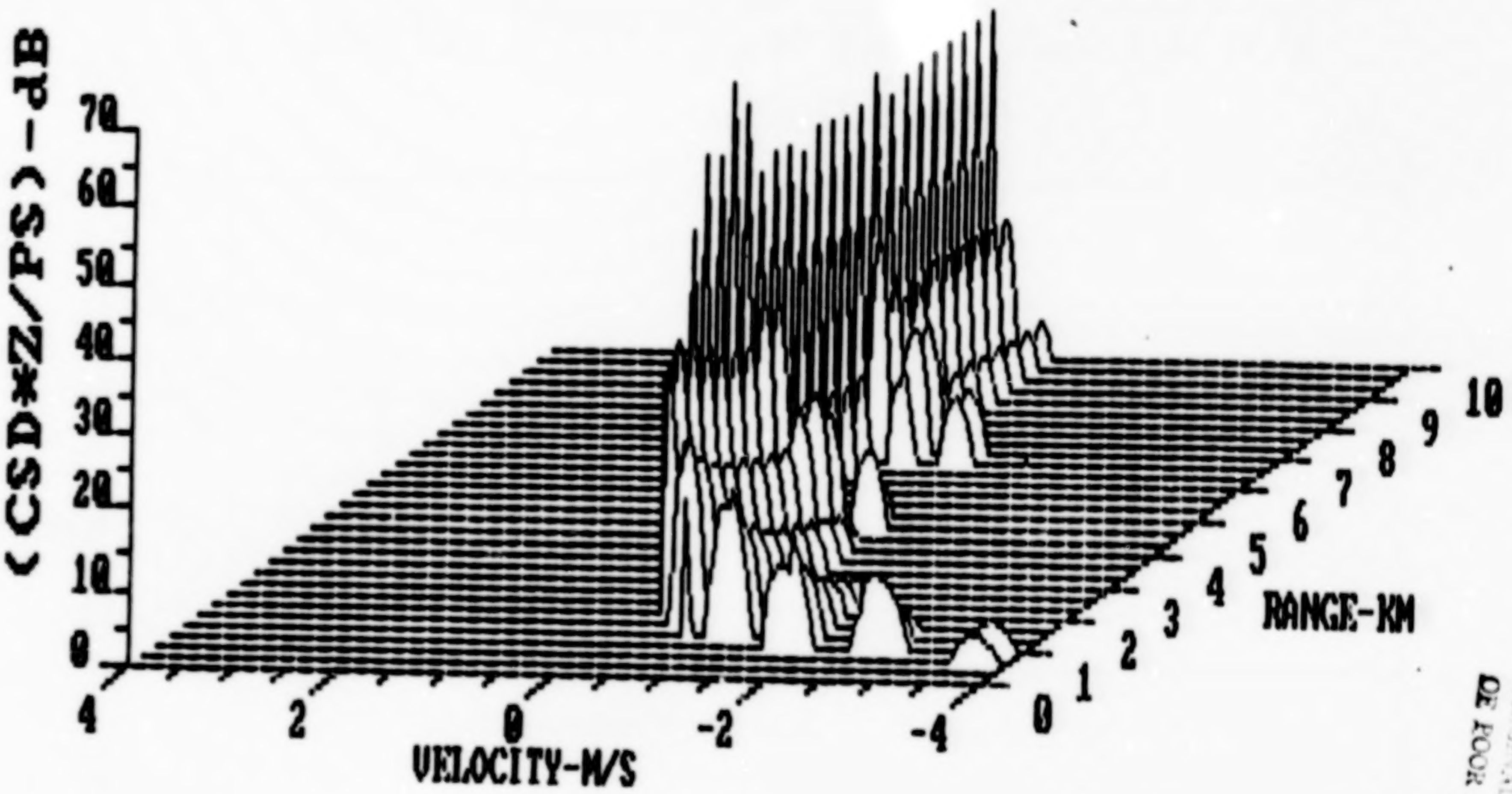


NORMALIZED CLUTTER SPECTRAL DENSITY

A/C RANGE TO TD = 5 KM (t = 62.5 sec.) ANT. EL. & AZ. =-3, & 0 deg. 02-21-1987



= .7 M E=-10 dB Go=-45 DB θb= 2.71608 DEG
e=-3 DEG θa= 0 DEG θs= 0 DEG
Z= 0 dBZ V= 80 M/S Vo= 80 M/S VN= 40.29[illegible] M/S
LX= 5

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Ad= .7 M E=-10 dB Go=-45 DB

e=-3 DEG θa= 0 DEG θb= 4.732647E-02 DEG θs= 0 DEG

= 0 dBZ V= 80 M/S Vo= 80 M/S VN= 40.2947 M/S

NLX= 5 Rr= 4.6667 KM

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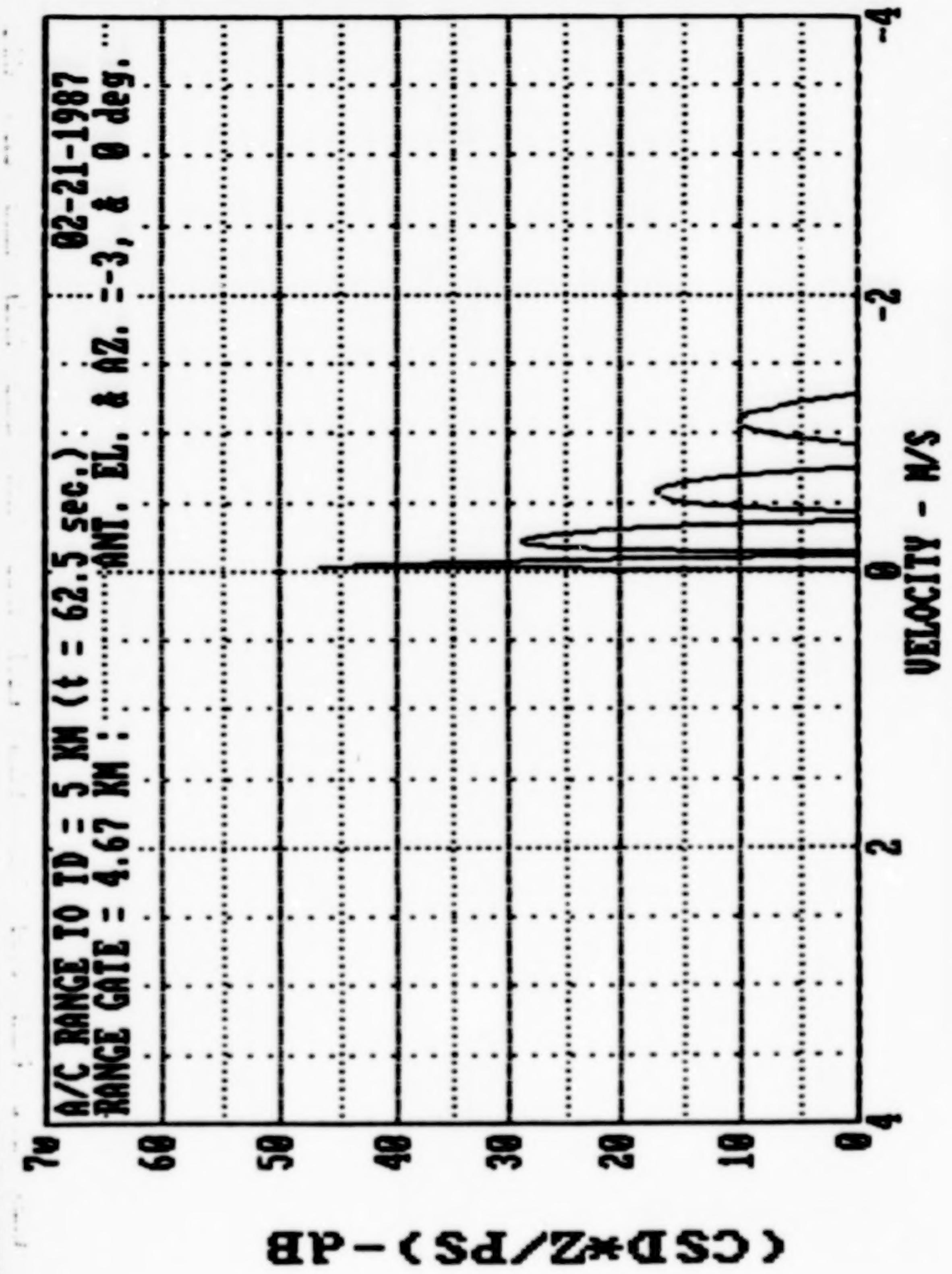

NORMALIZED CLUTTER SPECTRAL DENSITY; CSR*Z = 29.99 dB

```
Rt= 5 KM          0f=-3 DEG        Pd= 2 u-SEC        So= 200 u-SEC F= 9.3 GHz
Ad= .7 M          S=-10 dB         Go=-45 DB          0b= 2.711608 DEG
  =-3 DEG         0a=-10 DEG       0s= 9.966813 DEG
  - 0 dBZ         V= 80 M/S        Vo= 78.78782 M/S              VN= 40.2947 M/S
NLX= 5
```

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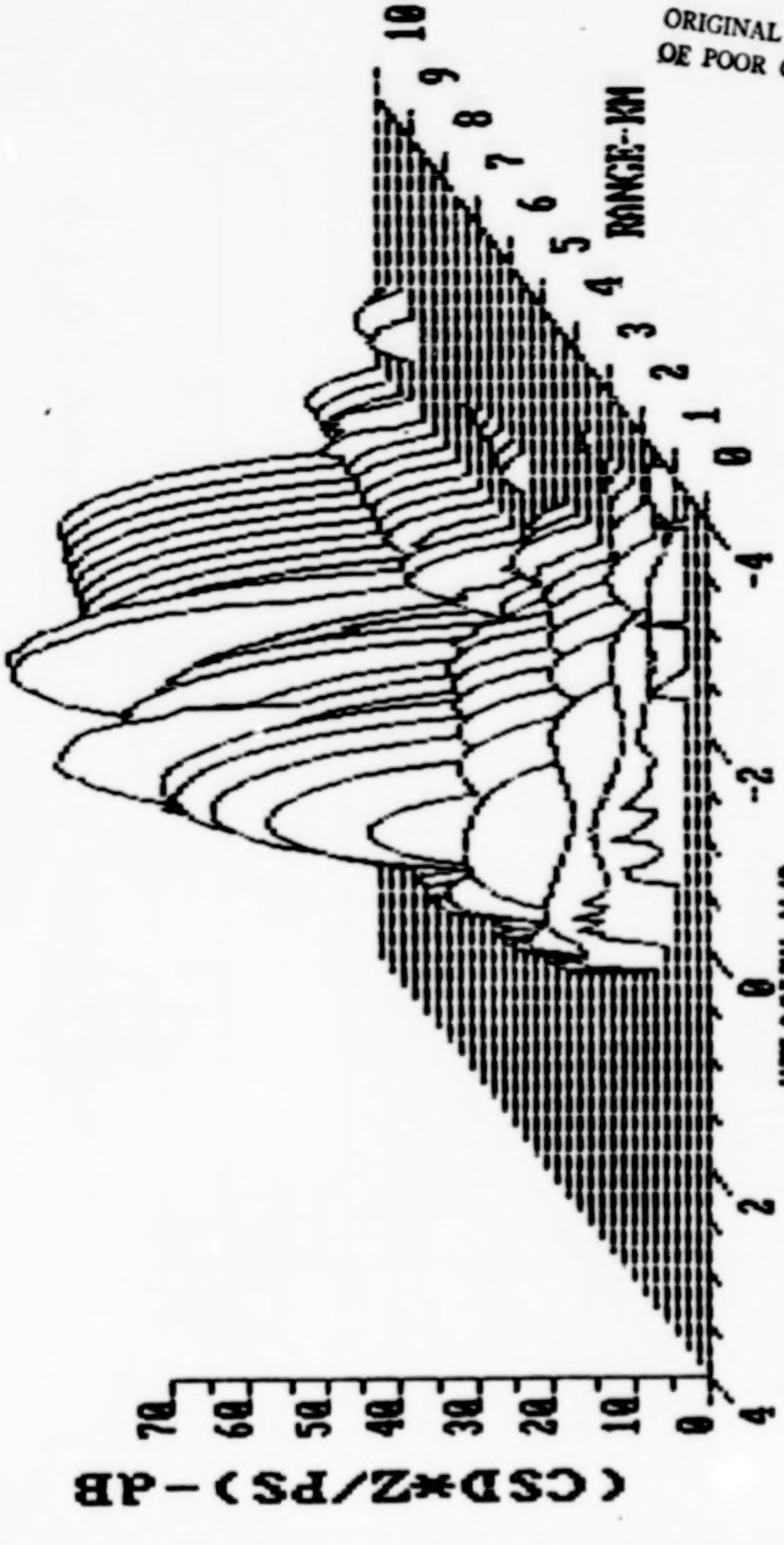
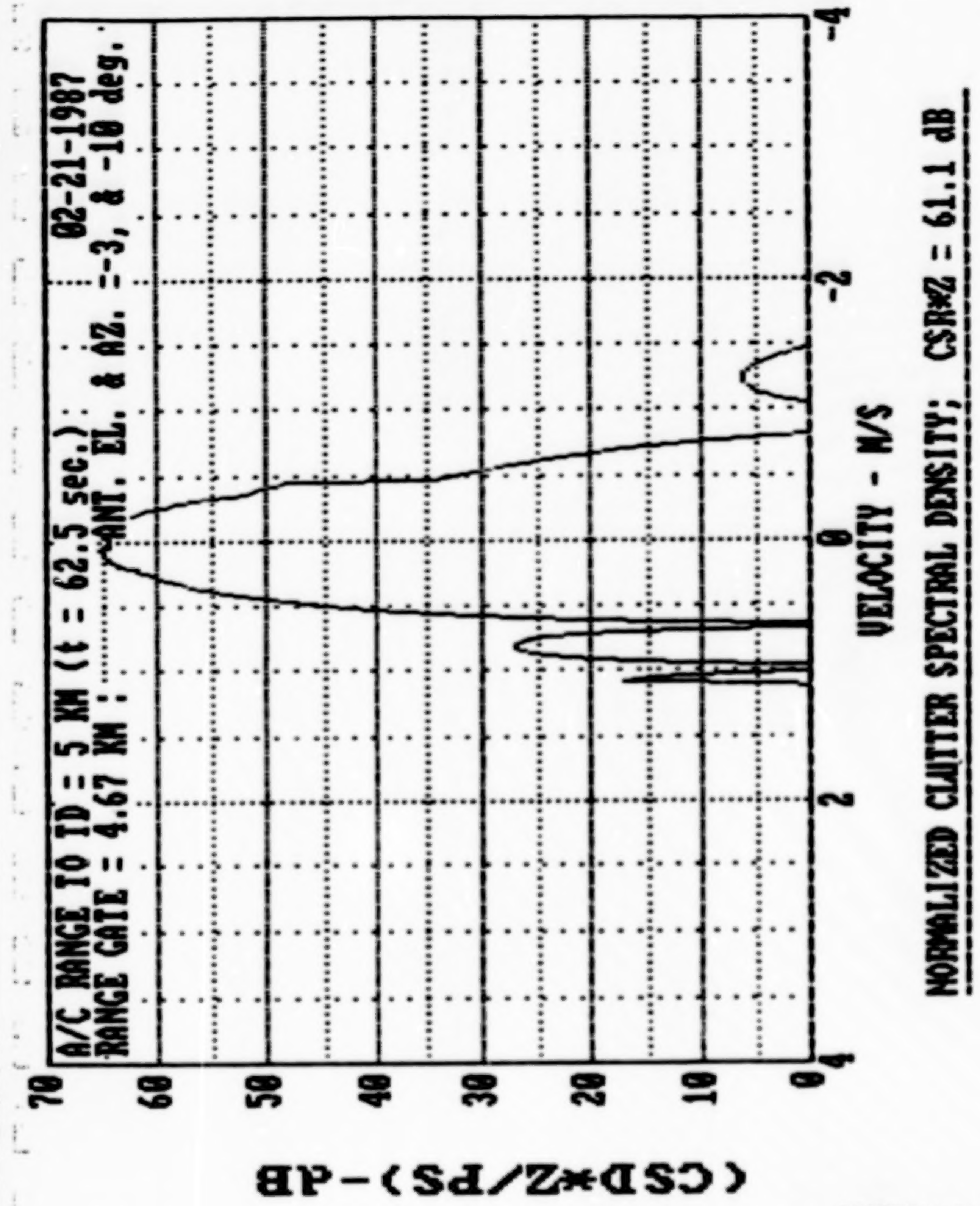
NORMALIZED CLUTTER SPECTRAL DENSITY 02-20-1987

A/C RANGE TO TD = 5 KM (t = 62.5 sec.) ANT. EL. & AZ. =-3, & -10 deg.



```
Rt= 5 KM        Of=-3 DEG       Pd= 2 u-SEC    Sp= 200 u-SEC F= 9.3 GHz
[illegible]1= .7 M        E=-10 dB        Go=-45 DB
[illegible]=-3 DEG      Oa=-10 DEG      Ob= 4.732647E-02 DEG          Os= .1743927 DEG
Z= 0 dBZ        V= 80 M/S       Vo= 78.78782 M/S              VN= 40.2947 M/S
[illegible]X= 5   Rr= 4.6667 KM
```



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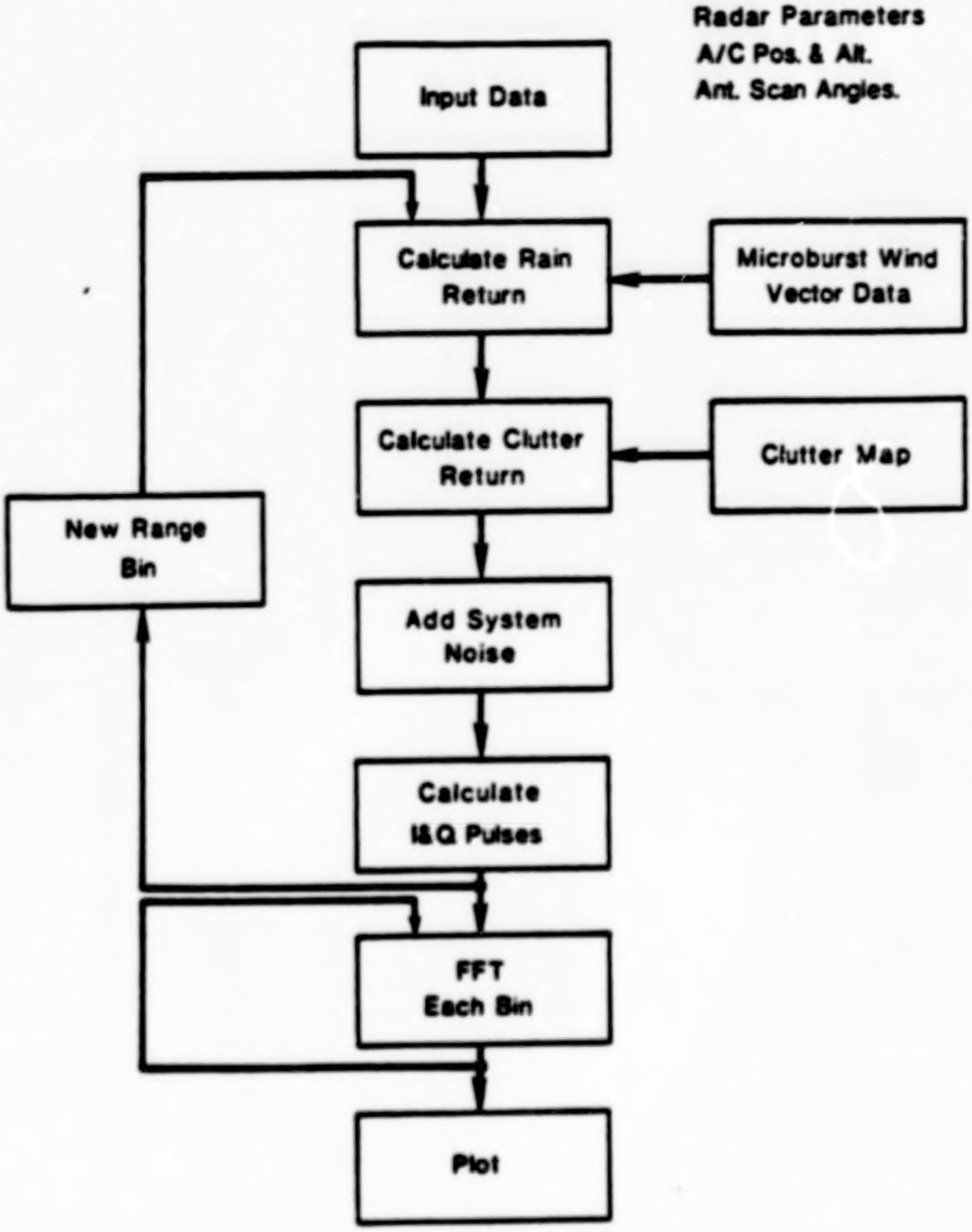
RADAR SIMULATION STUDIES
AT AMRB, NASA LARC

C. L. Britt
RTI at LaRC

RADAR SIMULATION



Radar Parameters
A/C Pos. & Alt.
Ant. Scan Angles.

Input Data

Calculate Rain Return

Microburst Wind Vector Data

Calculate Clutter Return

Clutter Map

New Range Bin

Add System Noise

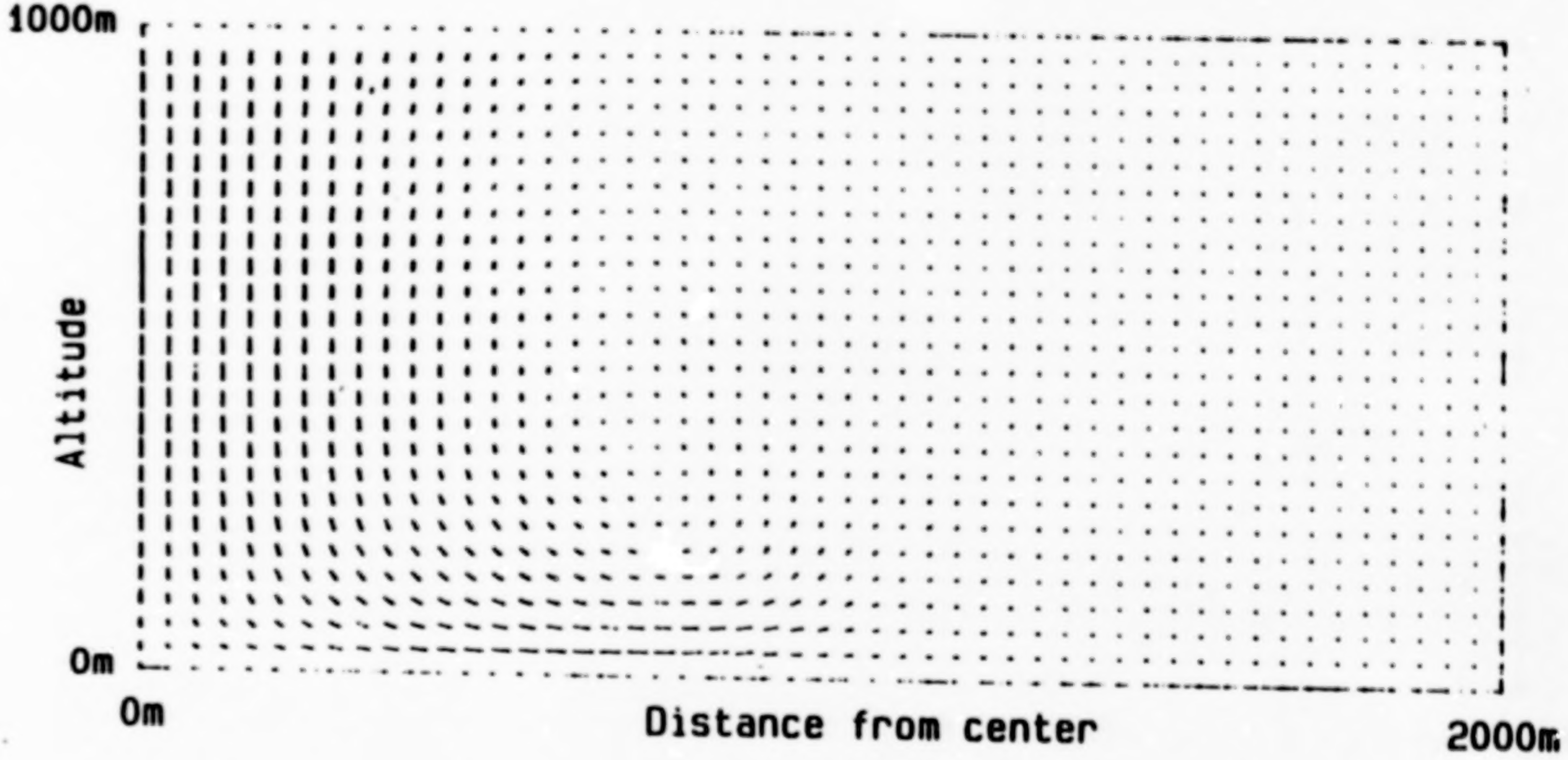
Calculate I&Q Pulses

FFT Each Bin

Plot

WIND VECTOR PLOT - MICROBURST "6MIN1"

Vector scale: 1 m/s = 1.5m
Plotting increment: 30m



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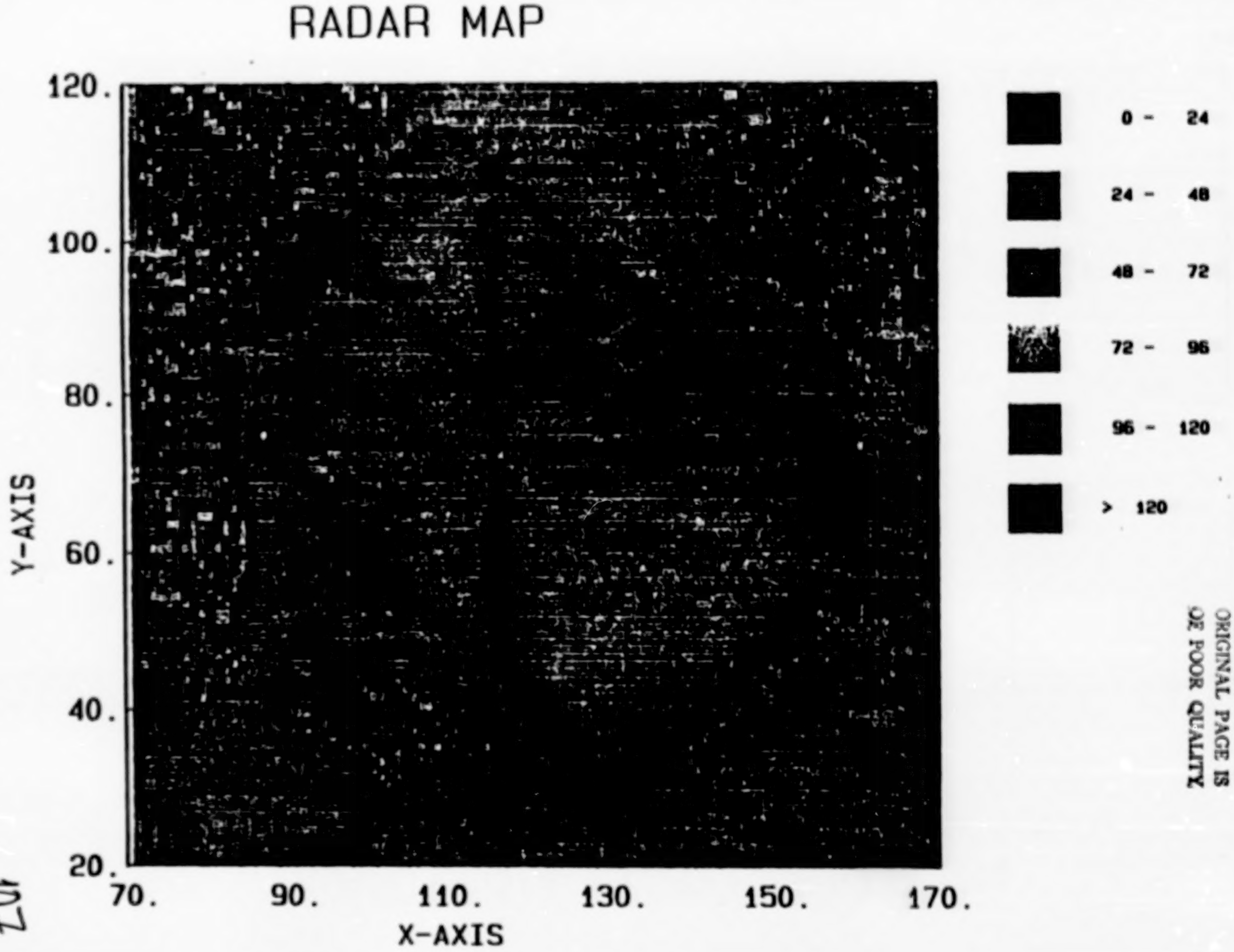

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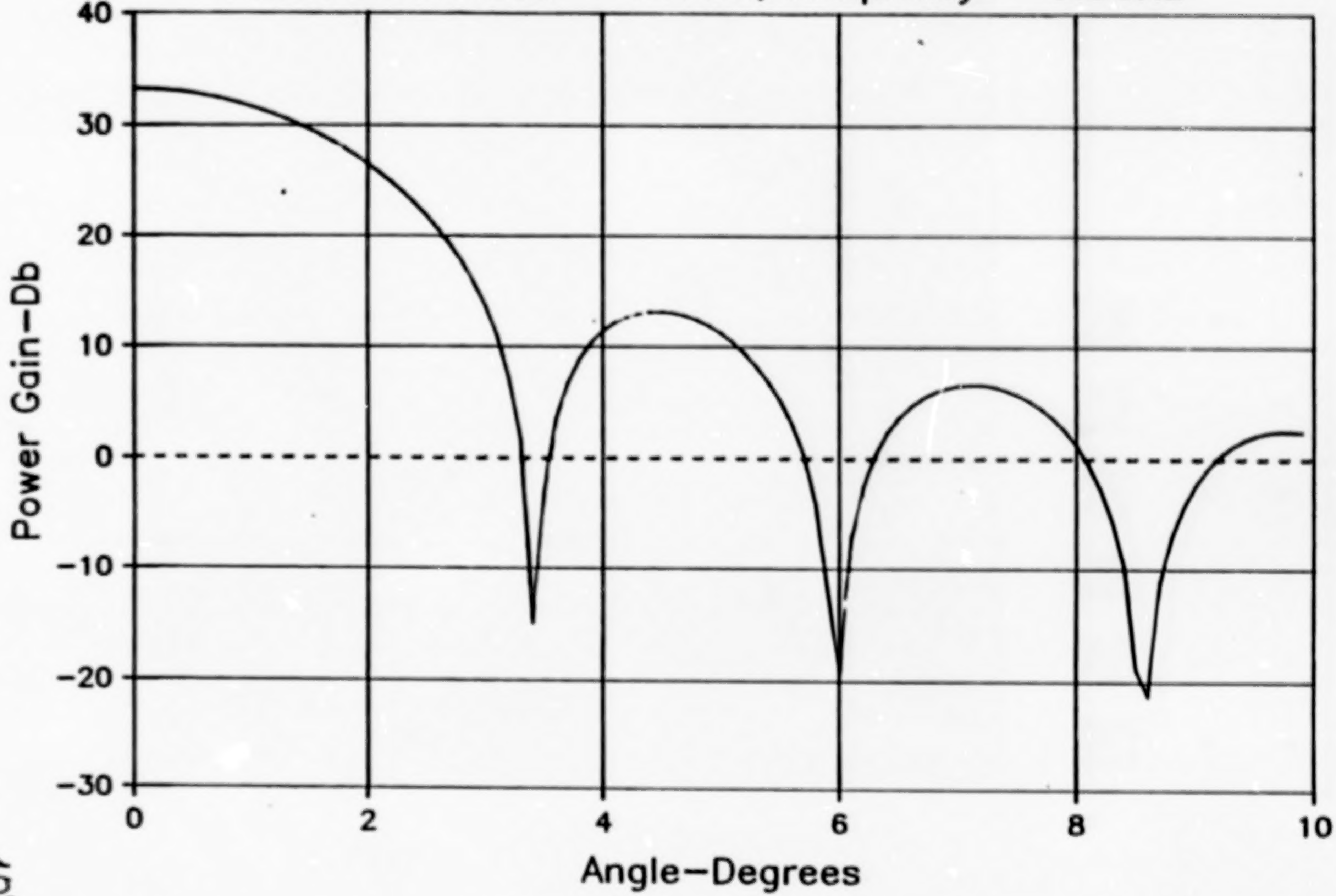
ANTENNA POWER PATTERN

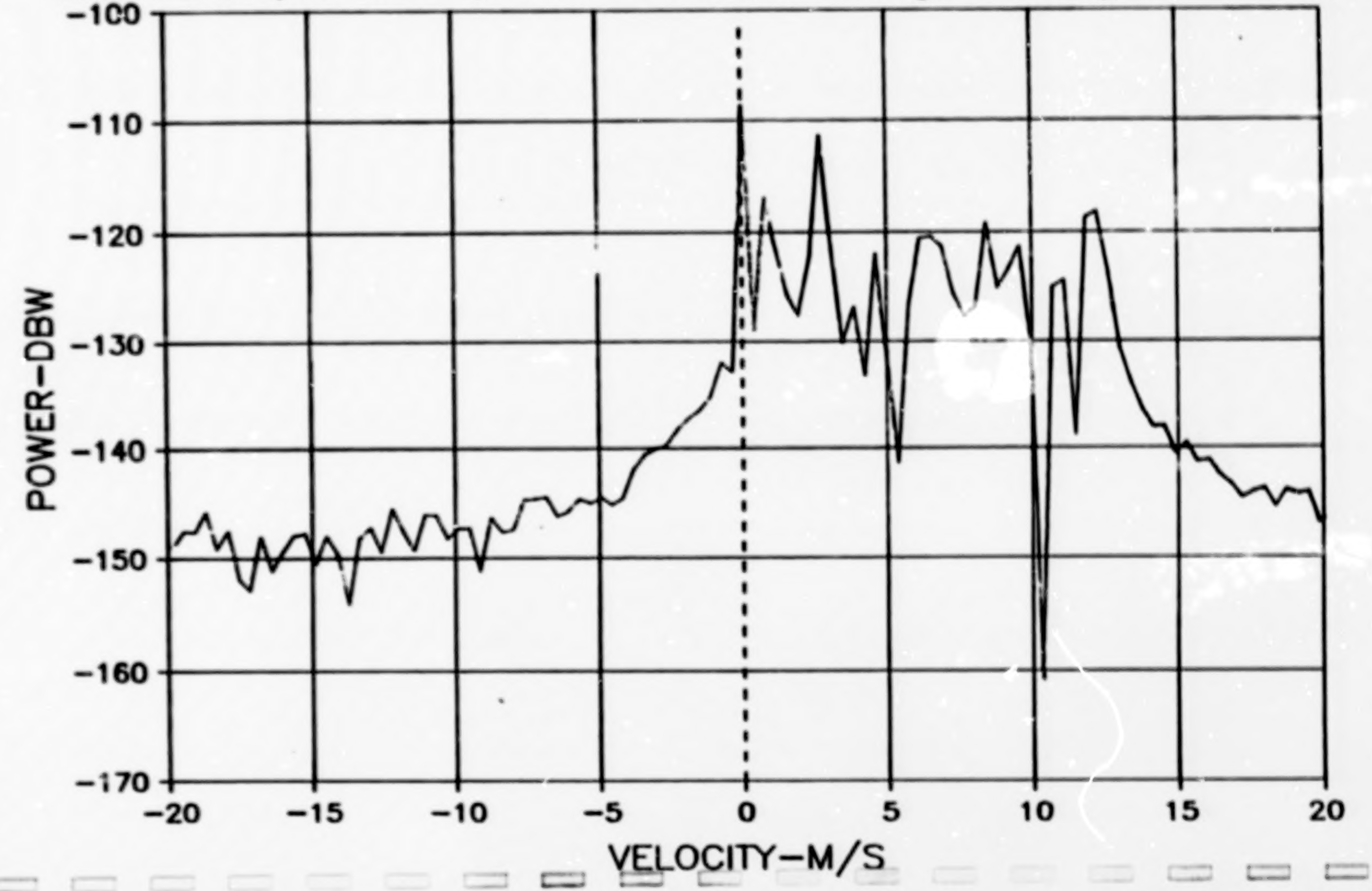
Antenna Diameter = .711m; Frequency = 9.3GHz



```
A/C RANGE (KM)          10.00
RADAR RG (KM)           9.0
A/C VEL (KTS)           140.
GLIDESLOPE (DEG)        3.
ROLL (DEG)              0.
PITCH (DEG)             0.
YAW (DEG)               0.
ANT AZ (DEG)            0.0
ANT EL (DEG)            0.0
TRANS PWR (WATTS)       2000.
FREQUENCY (GHZ)         9.3
P WIDTH (MICROSEC)      1.
P INTERVAL "            330.
RCVR NF (DB)              6.
NO. PULSES              128.
ANT RADIUS (M)          .3555
ANT "B" PARAMETER       .316
DELTHT (DEG)            .2
DELRG (M)                50.
THTMAX (DEG)             10.
RN SEED (0-1.)          .224
ZMAX (M)                600.
DELZ (M)                60.
RAIN RATE (MM/HR)       20.
RAIN VEL (M/S)          5.
RAIN SD (M/S)           0.
VEL OFFSET (M/S)        0.
```

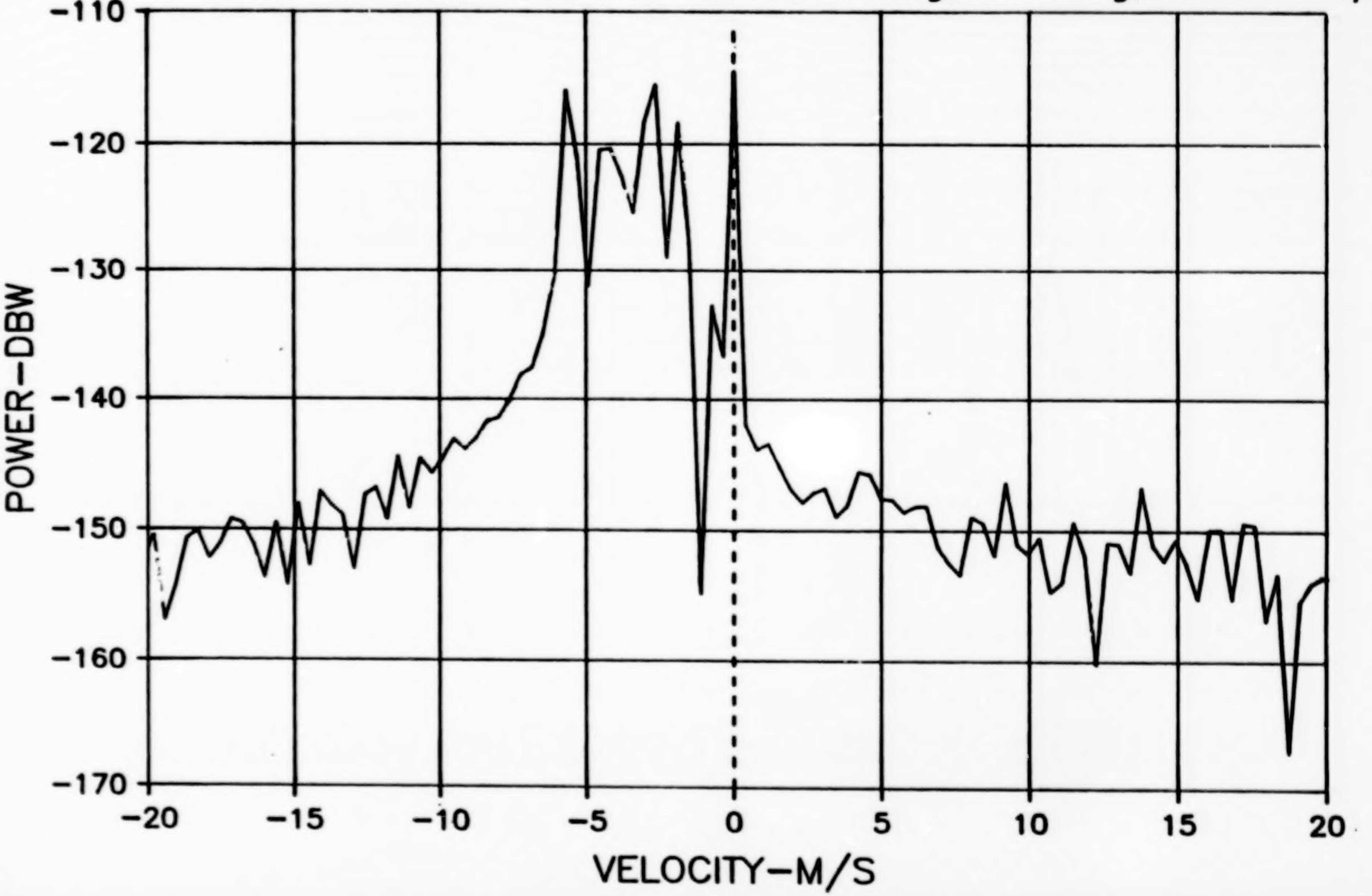
POWER SPECTRUM–RAIN + CLUTTER

VEL=140kts,RG=10km,RGBIN=9.0km,PIT=0deg,AZ=0deg,RR=20mm/s



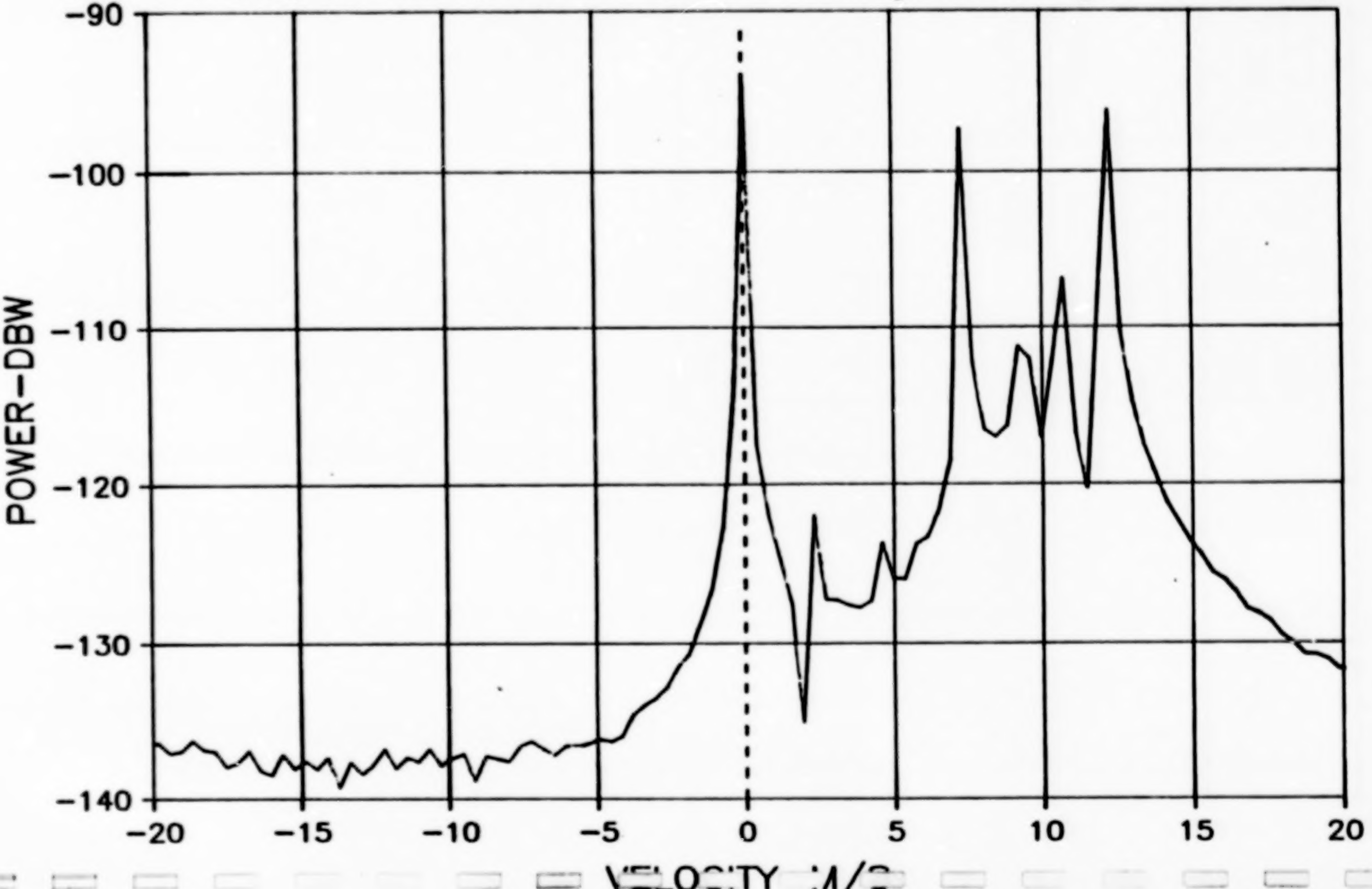
POWER SPECTRUM—RAIN + CLUTTER

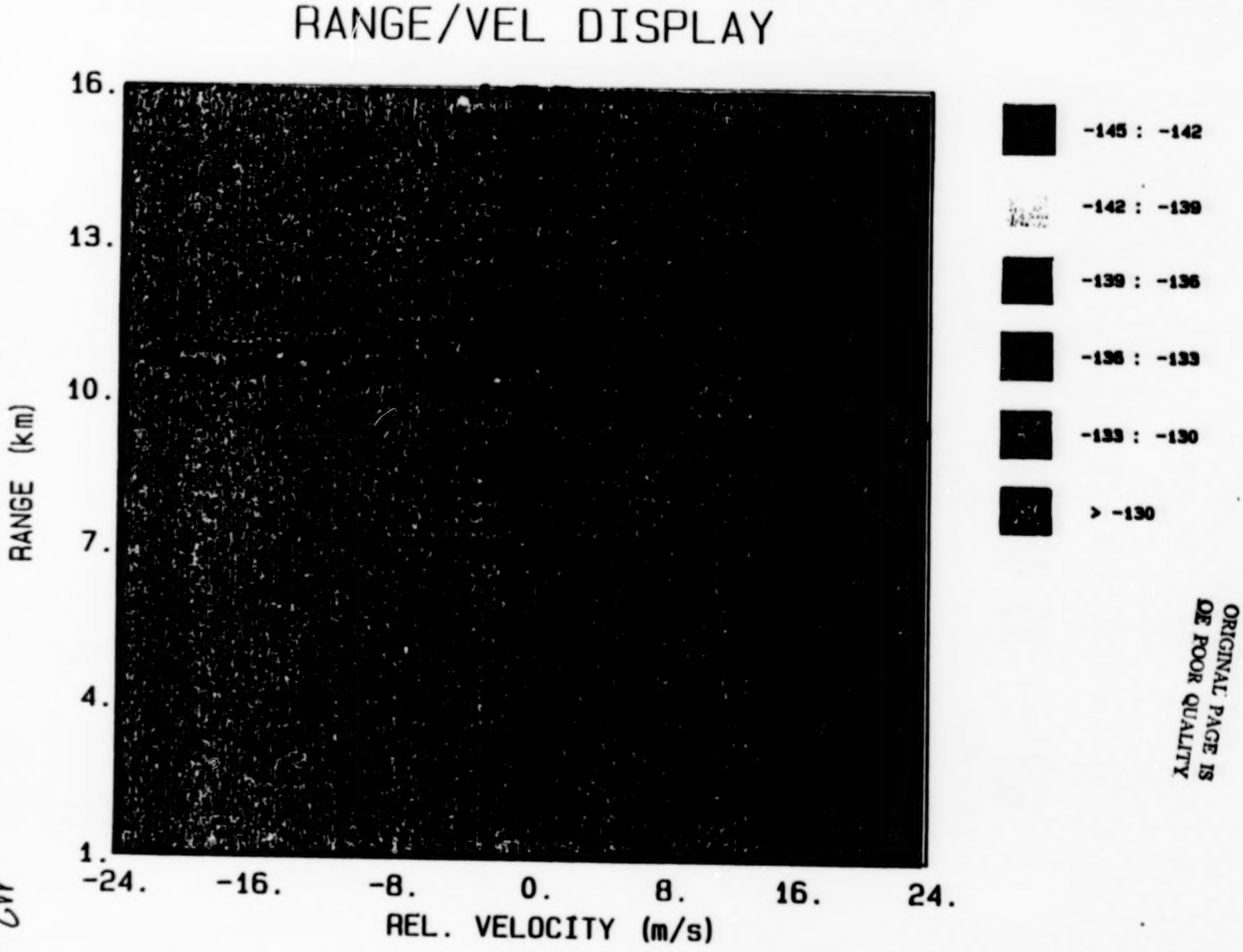
VEL=140kts,RG=10km,RGBIN=11.0km,PIT=0deg,AZ=0deg,RR=20mm/s



POWER SPECTRUM—RAIN + CLUTTER

VEL=140kts,RG=3km,RGBIN=2km,PIT=0deg,AZ=0deg,RR=20mm/s





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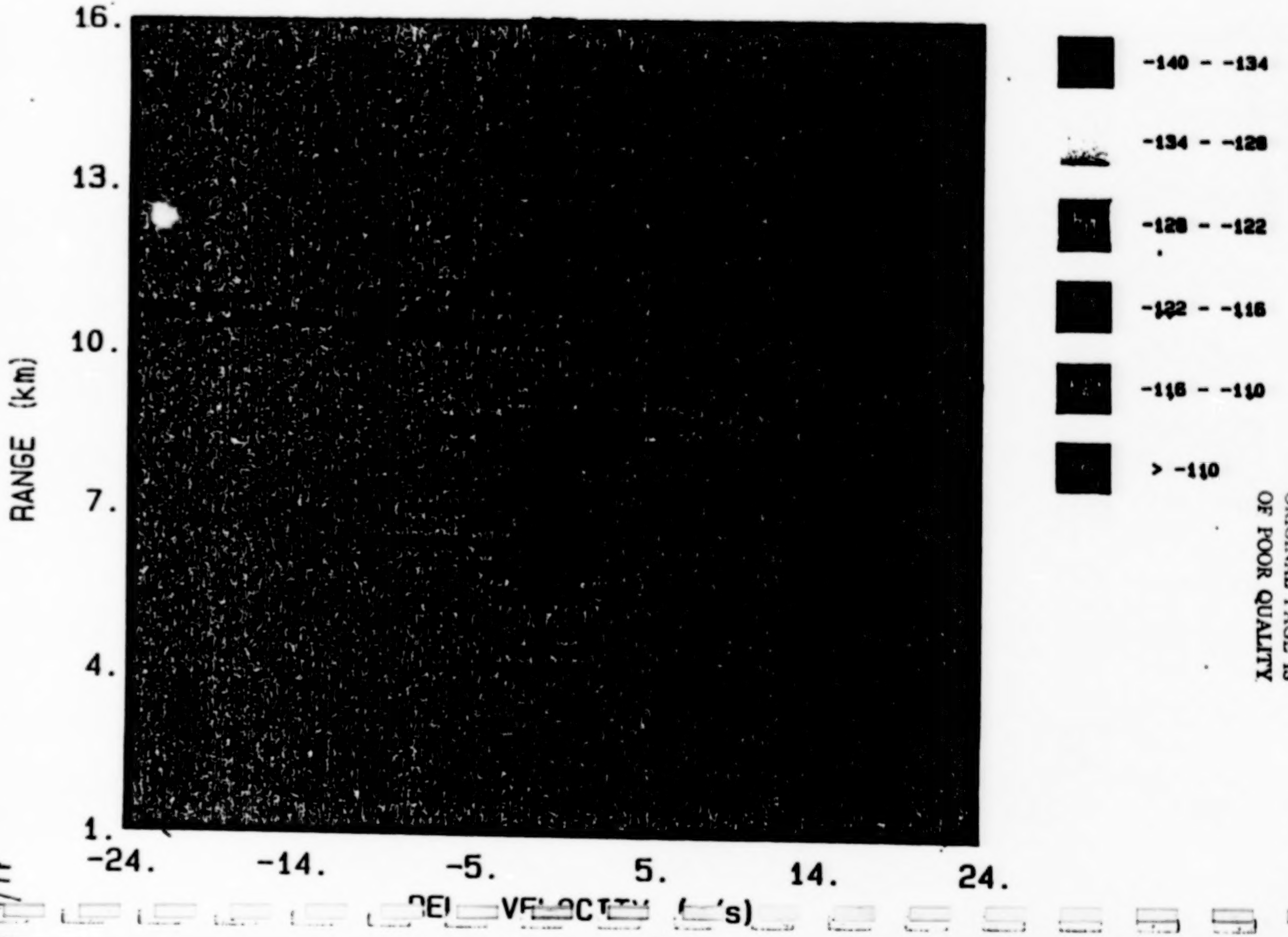
RANGE/VEL DISPLAY



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RADAR APPLICATION ISSUES

P. Hildebrand
NCAR

National Center for Atmospheric Research
P.O. Box 3000, Boulder, Colorado 80307

29 January 1987

Mr. Herb Schlickenmaier
CODE FAA/APM-430
Room 727
800 Independence Avenue
Washington D.C. 20591

Dear Herb:

The suggested topics for discussion for the FAA/NASA Forward Look Technology Symposium are enclosed in an unmarked plain brown envelope. Please forgive me if I went a little overboard in the scope of topics; however, the mind is a wonderful thing and can ramble all over the place.

See you soon.

Sincerely,

Peter

Peter H. Hildebrand
Manager, Airborne Doppler Radar Development Project
phone: 303-497-1031

cc: McCarthy

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Suggested Topics for Discussion
FAA/NASA Wind Shear Forward Look Technology Symposium

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I. Forward Look Technology

A. Specification of meteorological features to be observed
  1. Types of features
    a. winds
    b. temperature
    c. moisture
    d. precipitation
    e. opacity at different wavelengths
    f. reflectivity at different wavelengths
  2. Domain of features (x,y,z,t)
  3. Natural scales and gradients of distinctive features within domain (x,y,z,t)

B. Measurement Capability Specification
  1. Range
  2. Range resolution
  3. Range folding and sidelobes
  4. Angular (az & el) scan
  5. Angular resolution
  6. Angular sidelobes
  7. Measurement resolution
  8. Measurement domain
    a. Likelihood of folding
    b. Ability to unfold
  9. Measurement update or sampling rate
  10. Calculation cycle time
  11. Effects of inhibiting factors
    a. Rain
    b. Haze
    c. Ground clutter
    d. Other sidelobe effects
    e. Background measurement & system noise
    f. Maintainability of measurement system
      (1) failure rate
      (2) capabilities of typical maintenance crews to correctly maintain equipment
  12. System effectiveness for pilots
    a. Clearness/simplicity of output data
    b. Projected false alarm rate.
    c. Effect of measurement false alarm rate on pilot willingness to use data
    d. Need for interpretive intelligent display systems

Suggested Topics for Discussion
FAA/NASA Wind Shear Forward Look Technology Symposium

C. Forward Look Measurement Systems
  1. Microwave Doppler weather radar
  2. Doppler Lidar
  3. IR temperature sensing systems
  4. Other options

D. In-situ Measurement Systems
  1. Aircraft winds
  2. Ground speed
  3. Temperature
  4. Humidity
  5. Precipitation

II. Analysis and Display Options

A. Data processing
B. Noise reduction techniques
C. Data display
D. Intelligent systems
  1. Derived data fields (e.g. range derivatives,...)
  2. Integration of forward look and in-situ information
  3. Auto-recognition of meteorological features
  4. Auto-guidance around or away from meteorological features
  5. Auto-takeover of aircraft to avoid meteorological features

III. Plans for Growth

A. Opportunities to design the system for growth
  1. Division of the system into convenient modules
  2. Space in the system for more modules
  3. Use of programmable machines so new algorithms can be implemented
  4. Use of CAD systems to ensure easy upgrades for hardware

B. Types of growth
  1. Simple --> Complex Systems. The potential for moving from single to multi-sensor systems.
  2. Dumb --> Smart Systems. The potential for the system to recognise dangerous situations and to recommend safe, evasive action.
  3. Passive --> Active Systems. The potential to use smart systems to guide the aircraft.

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WIND SHEAR CONSIDERATIONS
FOR THE FORWARD LOOKING SYSTEM

R. Robertson
Rockwell/Collins

ROCKWELL INTERNATIONAL
COLLINS

WINDSHEAR CONSIDERATIONS
for the
FORWARD LOOKING SYSTEM

FEBRUARY 24, 1987

ASSUMPTION

WINDSHEAR DETECTION IS POSSIBLE WITH RADAR, LIDAR, IR SENSORS, INTERFEROMETER, ECT.

TARGET RECOGNITION

- TARGET CHARACTERISTICS AND STATISTICS
  - SIZE
  - REFLECTIVITY LEVELS
  - VELOCITY FACTORS
  - CLUTTER MASKING
- TARGET INTERPRETATION
  - MANUAL BY OBSERVER
  - AUTOMATIC DETECTION

SAFETY CONSIDERATIONS

FLIGHT CERTIFICATION

- MINIMUM OPERATIONAL PERFORMANCE STANDARD
  - ADAPTABLE TO DIFFERENT SYSTEM CONCEPTS
  - FLEXIBLE BUT PRECISE
- TESTS USING FAA GENERATED STANDARD TARGETS
  - COMPUTER SIMULATED DATA FOR CERTIFICATION TESTS
    - PSEDUO REAL WORLD AND STATISTICAL SIMULATIONS
      - METEOROLOGICAL PARAMETERS
      - AIRCRAFT PLATFORM PARAMETERS
      - USER SYSTEM PARAMETERS
      - BOTH DOMINANT AND MARGINAL TARGETS
- GROUND AND FLIGHT TESTS
  - MINIMUM CONSISTENT WITH ASSURED PERFORMANCE

WIND SHEAR AVOIDANCE WITH AN AIRBORNE LASER

R. Targ
Lockheed

LMSC-D067289

ALTOS

AIRBORNE LASER TURBULENCE OBSERVATION SYSTEM

WIND SHEAR AVOIDANCE

JANUARY 1987

Prepared by
RUSSELL TARG

Electro-Optical Sciences Directorate
Research & Development Division
LOCKHEED MISSILES & SPACE COMPANY, INC.
3251 Hanover Street
Palo Alto, California 94304

Note: pages 27 & 28 missing from original
page 40 blank, is not reproduced

THE NEW YORK TIMES, TUESDAY, JANUARY 17, 1984

Wind Bursts Blamed For Eight Air Accidents

SINCE 1964, a new study reveals, eight aircraft accidents related to sudden reversals in low-level wind direction have taken 514 lives. In one episode on Aug. 1, Air Force One, with President Reagan on board, landed at Andrews Air Force Base only six minutes before the base was struck by the most severe such wind change ever recorded.

A propeller-type anemometer near the north end of the runway went off scale at 130 knots (149 miles per hour), the highest wind velocity ever recorded by such a device.

THE NEW YORK TIMES, SUNDAY, AUGUST 3, 1986

Increasing Concern on Wind Shear Is Said to Cause More Flight Delays

By DENNIS HEVESI

Pilots, air traffic controllers and airline operators are warier than ever of thunderstorms and potentially disastrous wind shears, the sudden shifts of wind that can slam a low-flying plane to the ground, and their caution has led to more delays on landings and takeoffs, according to officials of the Federal Aviation Administration and the Airline Pilots Association.

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THE WIND SHEAR PROBLEM

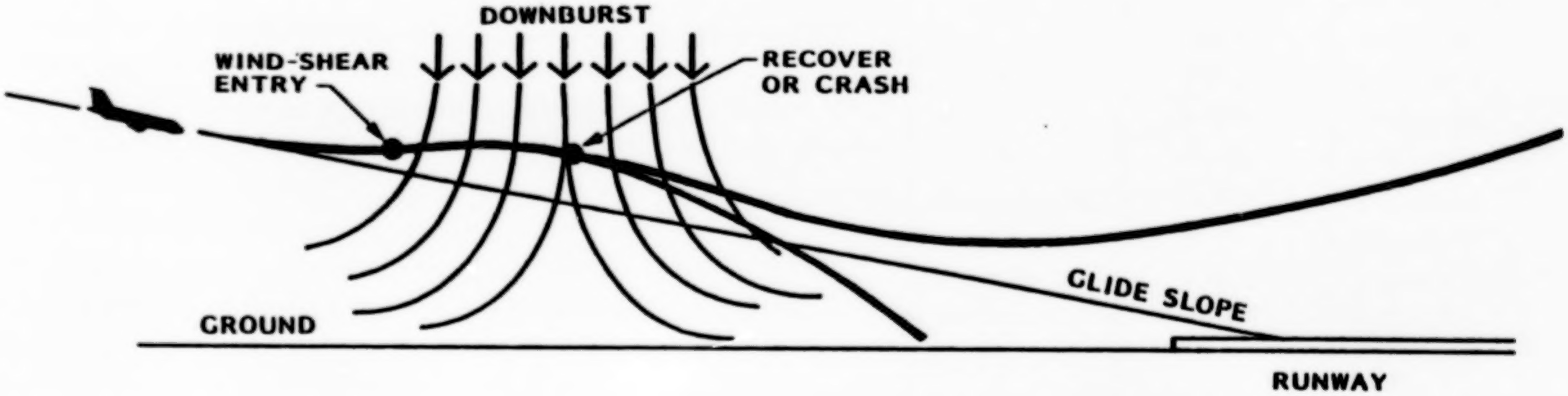
The crash in August 1985 of Delta Air Lines Flight 191, a Lockheed L-1011, at the Dallas/Ft. Worth International Airport focused national attention on the critical problem of detecting and avoiding wind shear.

As the pilot sees it, wind shear rapidly changes the direction of the wind on his glide slope. The downburst shown in the figure can be entirely invisible to the pilot and the ground controllers. In a NASA/FAA study of 186 wind-shear occurrences in 1983, the average change in velocity was approximately 40 miles per hour. That is, after the pilot has crossed the outer marker, his 20-mph head wind could turn into a 20-mph tail wind. If he is landing at 160 mph, this is a 25 percent drop in air speed, and a 50 percent reduction in lift. It is a situation from which a pilot frequently cannot make a recovery.

Pilots now receive inconsistent wind-shear warnings that are of questionable reliability. The effectiveness of warnings is further reduced by inconsistent terminology used by flight crews and busy control towers, and the fact that ground-based data must first be interpreted by trained meteorologists. The tower attempted to warn Flight 191 of wind shear, a full 2 minutes after it crashed.

It is therefore essential to emphasize avoidance rather than recovery. An onboard forward-looking wind-shear avoidance system can warn the pilot at the location marked "wind shear entry" that he is approaching a wind hazard. Informing him at location "recover or crash" that he is in wind shear, can be too late.

THE WIND SHEAR PROBLEM



INCIDENTS RELATED TO SHEAR CONDITIONS

LOCATION	DATE	AIRLINE	EQUIPMENT	FATALITIES	FLIGHT PHASE
1. DALLAS/FT. WORTH	8/2/85	DELTA	L-1011	133	LANDING
2. DETROIT METROPOLITAN	6/13/84	USAIr	DC-9-31	NONE	LANDING
3. DENVER STAPLETON	5/31/84	UNITED	BOEING 727	NONE	TAKEOFF
4. TAU, MANUA, AMERICAN SAMOA	5/12/84	S. PACIFIC IS.	DHC-6	NONE	LANDING
5. NEW YORK LaGUARDIA	12/28/83	CONTINENTAL	BOEING 727	NONE	LANDING
6. NEW YORK LaGUARDIA	7/28/82	TRANS WORLD	BOEING 727	NONE	LANDING
7. MORTON, WYOMING	7/16/82	UNITED	DC-10	NONE	INFLIGHT
8. NEW ORLEANS INTERNATIONAL	7/09/82	PAN AMERICAN	BOEING 727	153	TAKEOFF
9. DAYTON, OHIO COX	5/21/82	USAIr	BAC 111	NONE	LANDING
10. TUCSON, ARIZONA INTERNATIONAL	6/03/77	CONTINENTAL	BOEING 727	NONE	CLIMB
11. WILDWOOD, NEW JERSEY	12/12/76	COMMUTER	DHC-6	3	FINAL
12. PHILADELPHIA INTERNATIONAL	6/23/76	USAIr	DC-9	NONE	GO-AROUND
13. DENVER STAPLETON	8/07/75	CONTINENTAL	BOEING 727	NONE	CLIMB
14. NEW YORK JFK	6/24/75	EASTERN	BOEING 727	113	FINAL

SOURCE: NATIONAL TRANSPORTATION SAFETY BOARD/AVIATION WEEK 8/12/85

AIRBORNE WIND SHEAR DETECTION: GENERAL REQUIREMENTS

- MEASURE X, Y, Z COMPONENTS OF WIND VELOCITY FROM AIRCRAFT
- DETECT THUNDERSTORM DOWNBURST EARLY IN ITS DEVELOPMENT
- EMPHASIZE AVOIDANCE RATHER THAN RECOVERY
- RESPOND IN REAL TIME WITH LOW FALSE-ALARM RATE
- MONITOR APPROACH PATH, RUNWAY, AND TAKEOFF PATH
- OPERATE IN BOTH RAIN AND CLEAR AIR CONDITIONS
- OPERATE RELIABLY WITH MINIMUM MAINTENANCE IN AIRCRAFT ENVIRONMENT
- MEASURE AIRSPEED, ALTITUDE, AND SLANT RANGE

EVOLUTION OF THE MICROBURST FIELD

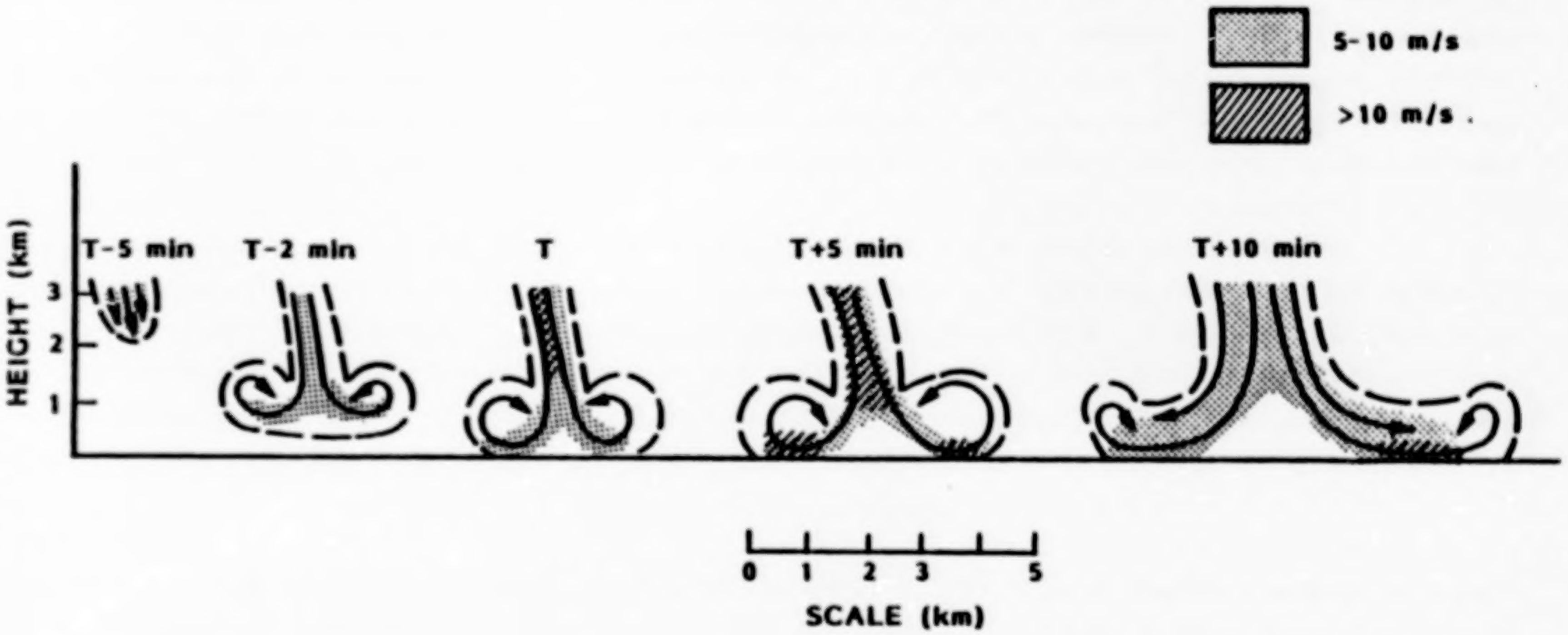
Congressional concern over the crash of a Pan American World Airways Boeing 727, minutes after takeoff from the New Orleans International Airport on July 9, 1972, resulted in an agreement between NASA and FAA to study and assess the hazards of low-altitude wind shear.

This resulted in the 1983 Joint Airport Weather Study (JAWS) at Denver/Stapleton airport in which wind shear was observed and measured over a 3-month period. The principal finding confirmed that "...low-altitude wind variability (or wind shear) presents an infrequent but highly significant hazard to aircraft landing or taking off...."

From analysis of aircraft accidents where low-altitude wind shear was a factor, it appears that the greatest hazards are caused by downdrafts and outflows produced by convective storms. Since 1964, the National Transportation Safety Board (NTSB) has documented at least 28 accidents or incidents, 15 of which have involved fatalities or serious injuries.

The figure illustrates data from the JAWS report of 1983. It shows that 2 minutes before a typical downdraft has started to significantly diverge, it is below 1 km. After 2 minutes the downdraft speed has increased to 10 m/s, the diameter is 1 km, and the differential velocity is 12 m/s over a distance of 1.8 km. After 7 minutes, the differential velocity has increased to 24 m/s (approximately 48 mph) and spread to 3.1 km.

VERTICAL CROSS SECTION OF THE EVOLUTION OF THE MICROBUST WIND FIELD*



*FROM THE JOINT AIRPORT WEATHER STUDIES PROJECT, OCTOBER 1983

LASER WIND VELOCITY MEASUREMENTS

In recent years there have been many advances in airborne laser velocimetry. James Bilbro, at NASA's Marshall Space Flight Center, has successfully measured wind velocity from an aircraft, using a modulated CO_2 cw laser followed by a high-power amplifier that produces 10-mJ pulses at 10.6 microns. Bilbro's Doppler lidar operates in clear air, and has a range of more than 5 km. This pioneering system makes use of laser technology developed in the 1970's, and as a result is a very large system.

A compact and reliable laser system has been flight-tested for several years by J. Michael Vaughan of the Royal Signals and Radar Establishment, Great Melbourne, Worcester, England. His lidar used a c-w CO_2 laser focused 300 meters in front of the airplane. Like Bilbro, Vaughan uses optical heterodyne detection to determine the plane's velocity from the Doppler shift in the radiation scattered from the aerosols illuminated by the laser. Because it is a c-w, focused system, it is unable to give range information, and its look-ahead is limited to only a few seconds warning.

In the past 2 years, pulsed, transversely excited, atmospheric pressure (TEA) lasers have been made increasingly compact and reliable. Such a system has been used with good success by R. Michael Hardesty at NOAA to measure wind velocity and map wind fields with a lidar system located in a van. Similar systems using smaller lasers could be developed for airborne systems. We have analyzed one such system which would use a Q-switched CO_2 laser in which the laser, the optics, and detector package can be assembled into a 2.5 ft^3 volume.

SUCCESSFUL MEASUREMENT OF WIND VELOCITY WITH EXISTING DOPPLER LIDARS

RESEARCHER	ORGANIZATION	SYSTEM	TIME PERIOD
DAVID WILSON	LOCKHEED	COMPACT GROUND-BASED VELOCIMETER	1976-85
MICHAEL VAUGHAN	RRE	COMPACT AIRBORNE VELOCIMETER	1979-86
JAMES BILBRO	NASA	AIRBORNE WIND FIELD MAPPING	1980-86
MICHAEL HARDESTY	NOAA	GROUND-BASED WIND FIELD MAPPING	1981-86

TENTATIVE TECHNICAL REQUIREMENTS

It is desirable for the pilot to have the maximum possible time to make an informed decision as to whether he will land or go around. If we consider an approach velocity of 100 meters per second (approximately 200 mph), then a 3-km look-ahead range will give the pilot 30 seconds warning of a wind-shear hazard ahead. From our conversations with airline and military pilots, it appears that 30 seconds is optimum warning time. A longer warning time would not be appropriate since the formation of wind shear is dynamic, and will be changing on a time scale comparable to 30 seconds. Lockheed has designed an Airborne Laser Turbulence Detection System (ALTOS) to meet these requirements.

The ALTOS system described here can give the pilot information about the wind-shear threat from his present position, extending 3-km ahead. This can be conveniently accomplished by measuring and displaying five 300-meter segments of the flight path.

To make a land/no-land decision, it is sufficient to measure wind velocity to an accuracy of 2 meters per second (approximately 4 mph). The ALTOS flight computer will continuously update the wind-shear display and alert the pilot by auditory signals if there is a wind-shear hazard without the need to monitor the sensing equipment or display.

TENTATIVE TECHNICAL REQUIREMENTS

• SENSING RANGE	1 TO 3 km
• RANGE RESOLUTION	0.3 km
• VELOCITY RESOLUTION	APPROXIMATELY 2 m/s

LASER DEVICE TRADES: Nd:YAG VERSUS CO_2

CO2 LASER

ADVANTAGES:

- MATURE TECHNOLOGY
- ELECTRICAL EFFICIENCY 5 TO 8%
- NO EYE SAFETY PROBLEM

DISADVANTAGES:

- WEIGHT AND SIZE GREATER THAN IDEALIZED SOLID STATE SYSTEM

YAG LASER

ADVANTAGES:

- POTENTIALLY SMALL SIZE AND LIGHTWEIGHT
- SOLID-STATE RELIABILITY
- INCREASED MIE SCATTERING AS COMPARED WITH CO_2 CASE

DISADVANTAGES:

- NOT YET A MATURE TECHNOLOGY
- ELECTRICAL EFFICIENCY < 1 %
- NOISE EQUIVALENT POWER (NEP) 100 TIMES GREATER THAN CO_2 (NEP ~ $h\nu B$)
- EYE SAFETY LIMITS PULSE ENERGY TO $< 10^{-6}$ J/cm^2
- ATTENUATION >> CO_2 IN FOG

TENTATIVE SPECIFICATIONS

WAVELENGTH	10.6 µm
PULSE ENERGY	2 mJ.
PULSE DURATION	2 µs
PULSE REPETITION RATE	2 kHz
DETECTOR	HgCdTe
COOLING	MECHANICAL REFRIGERATOR
TELESCOPE DIAMETER	15 cm
TELESCOPE TYPE	OFF-AXIS PARABOLA
SCANNING CAPABILITY	15° NOMINAL
SIGNAL PROCESSING	ONLINE FFT

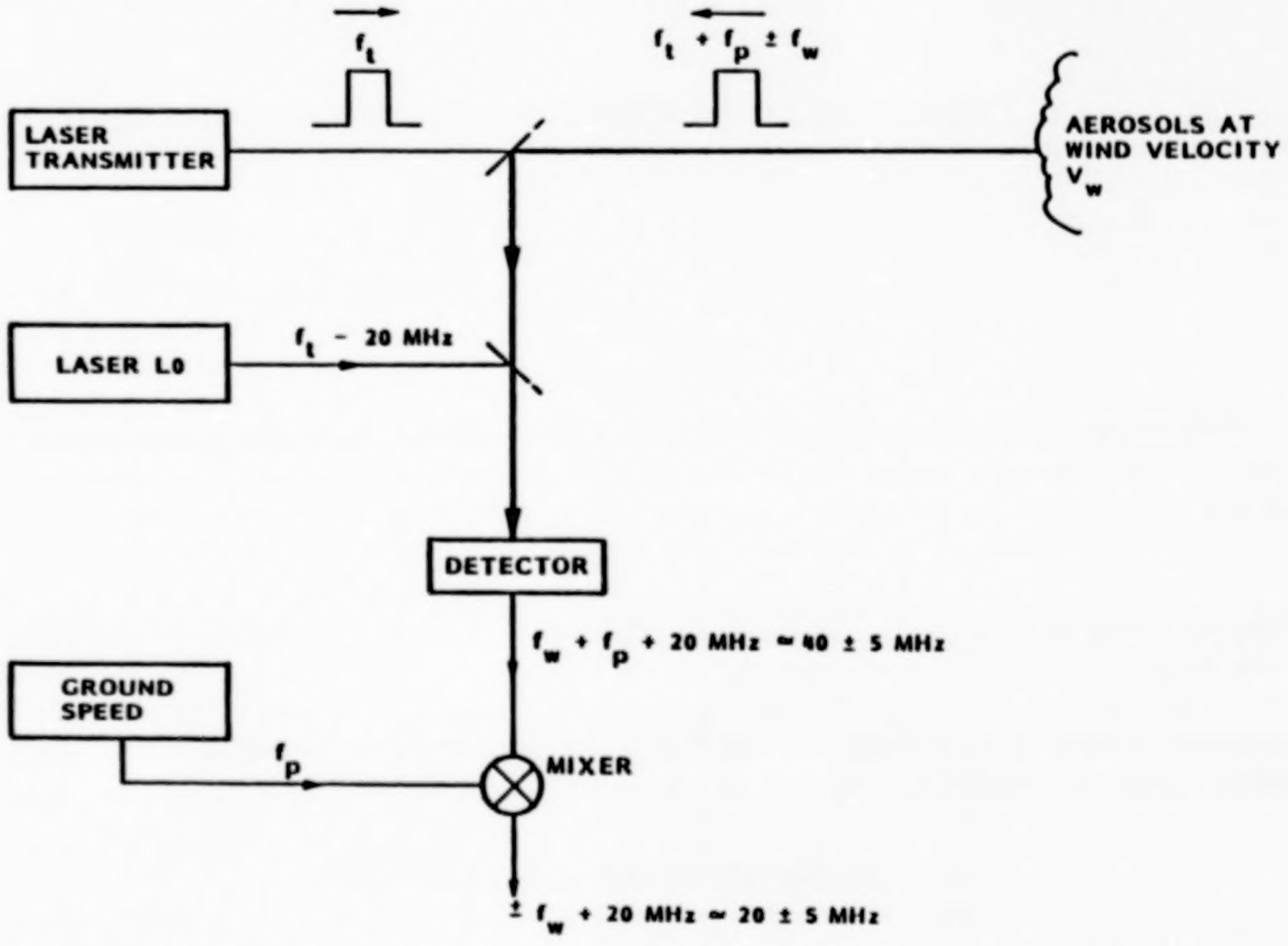
DOPPLER WIND VELOCITY MEASUREMENT

The ALTOS coherent detection system uses a CO_2 laser which transmits a train of 2-microsecond pulses at a 2-kHz rate. These transmitted pulses at a frequency f_t will be scattered by the aerosols in the air being illuminated. The optical signal will be Doppler shifted in frequency by an amount f_w, proportional to the wind velocity. An additional frequency shift f_p will occur due to the plane's velocity.

This signal at a frequency $f_t + f_w + f_p$ will be received by the transmitting telescope. It will then be detected and mixed with a stable laser local oscillator at a frequency $f_t + 20$ MHz to place the resulting beat well above baseband, and retain the direction as well as the velocity of the wind being sensed.

After photodetection, the signal will be mixed with an rf signal f_p determined by the onboard flight computer. This will subtract out the frequency component due to the plane's velocity. The resulting frequency will be the desired Doppler shift introduced by the wind velocity.

DOPPLER WIND VELOCITY MEASUREMENT

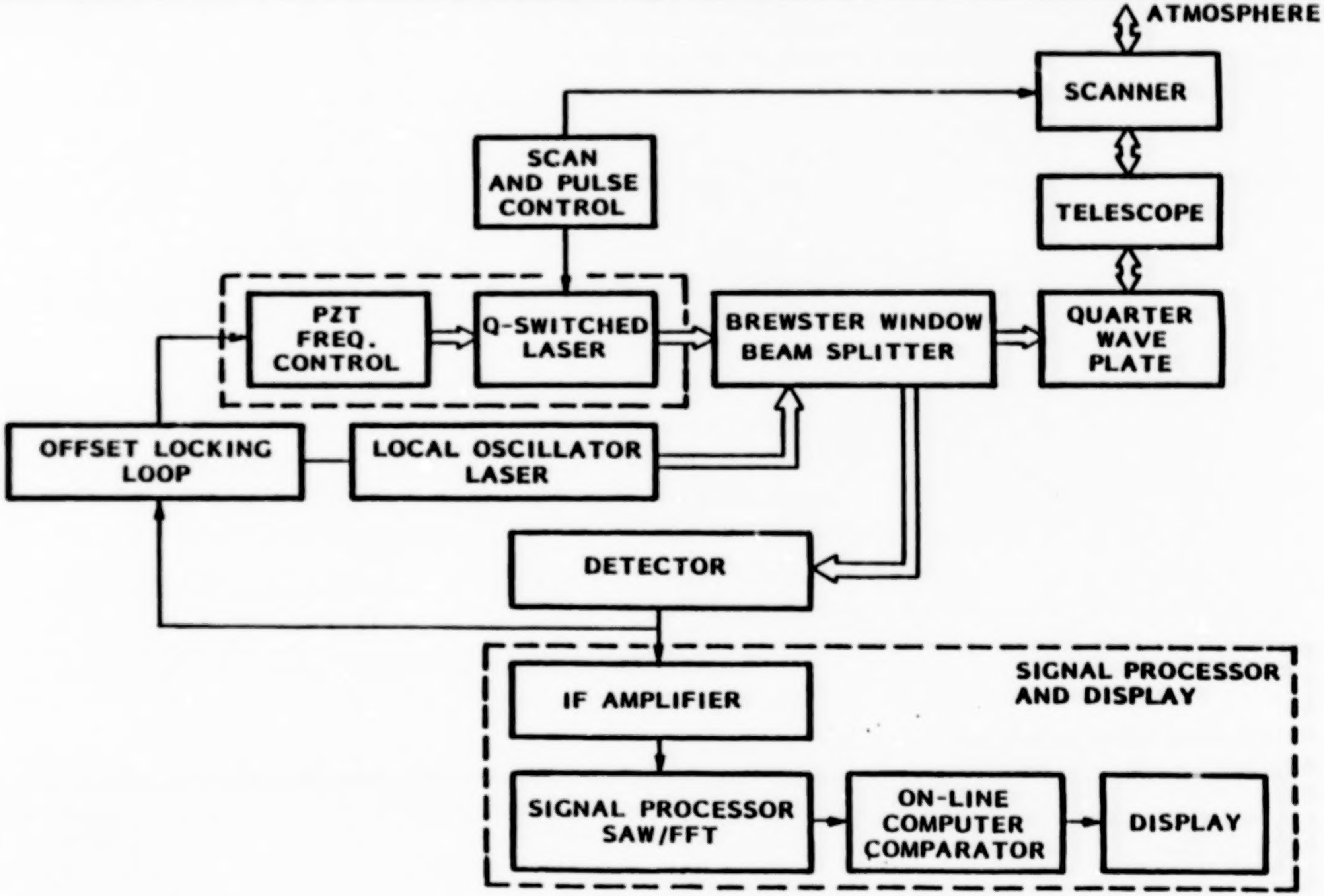

LASER TRANSMITTER
f_t
$f_t + f_p \pm f_w$
AEROSOLS AT WIND VELOCITY V_w
LASER LO
$f_t - 20$ MHz
DETECTOR
$f_w + f_p + 20$ MHz ≈ 40 ± 5 MHz
GROUND SPEED
f_p
MIXER
$\pm f_w + 20$ MHz ≈ 20 ± 5 MHz

COHERENT DETECTION WITH A Q-SWITCHED CO_2 LASER

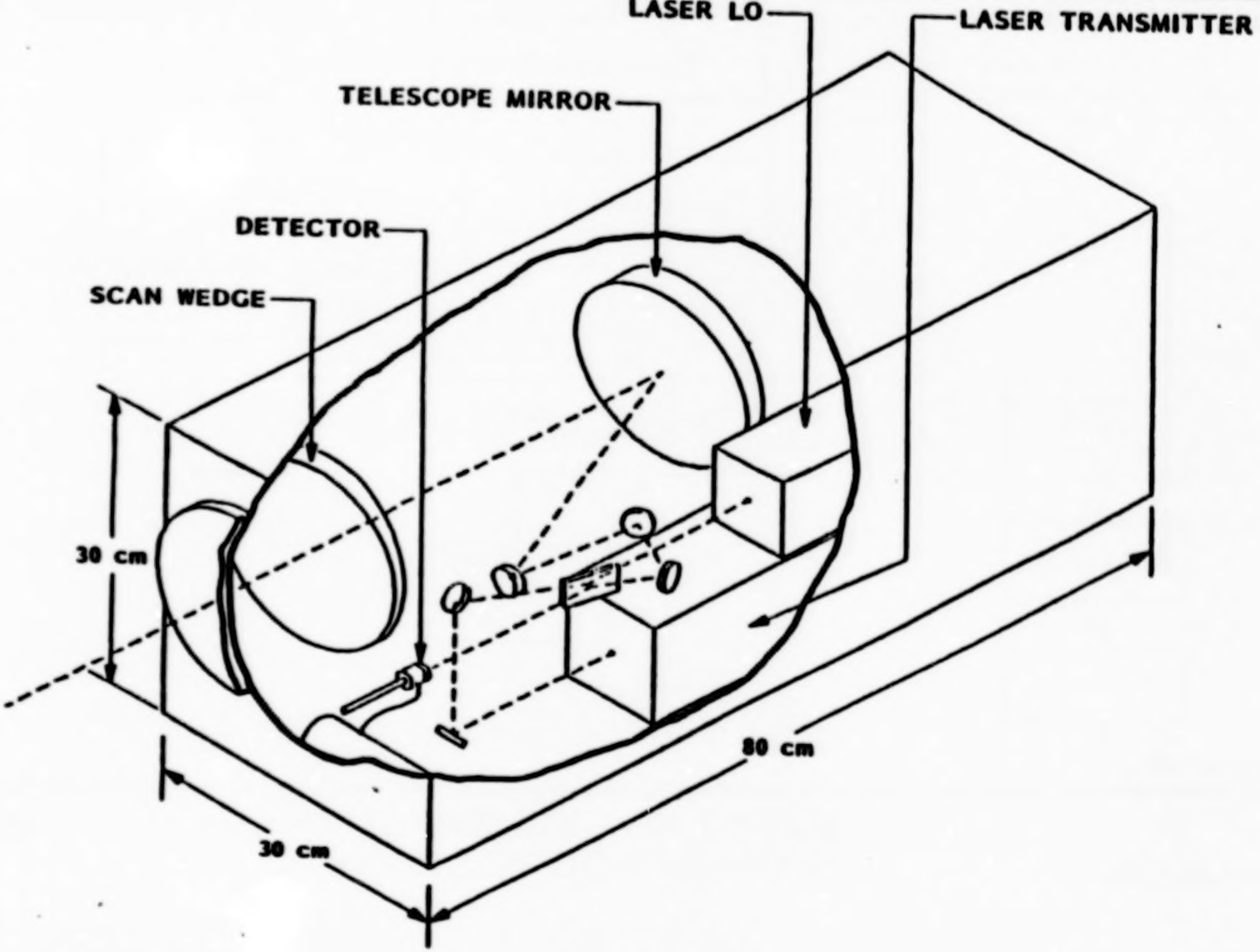
The ALTOS system uses a Q-switched CO_2 TEA laser as its signal source. A small frequency-stabilized CO_2 laser local oscillator controls the output frequency of the laser transmitter and maintains a precise frequency offset. The lasers are sealed, and are capable of 2,000 hours of operation. The HgCdTe detection will be cooled by a mechanical cooler. Neither liquid nitrogen nor compressed gas cooling is contemplated. All signal processing of the Doppler wind data will be completed in real time by the ALTOS onboard computer.

The entire laser package has a volume of 2.5 ft^3, and weighs less than 100 pounds. It is designed by Spectra Technology, who has built and delivered a similar, but higher power system, to NOAA this year. They also plan to use the system for wind-velocity measurements and wind-field mapping.

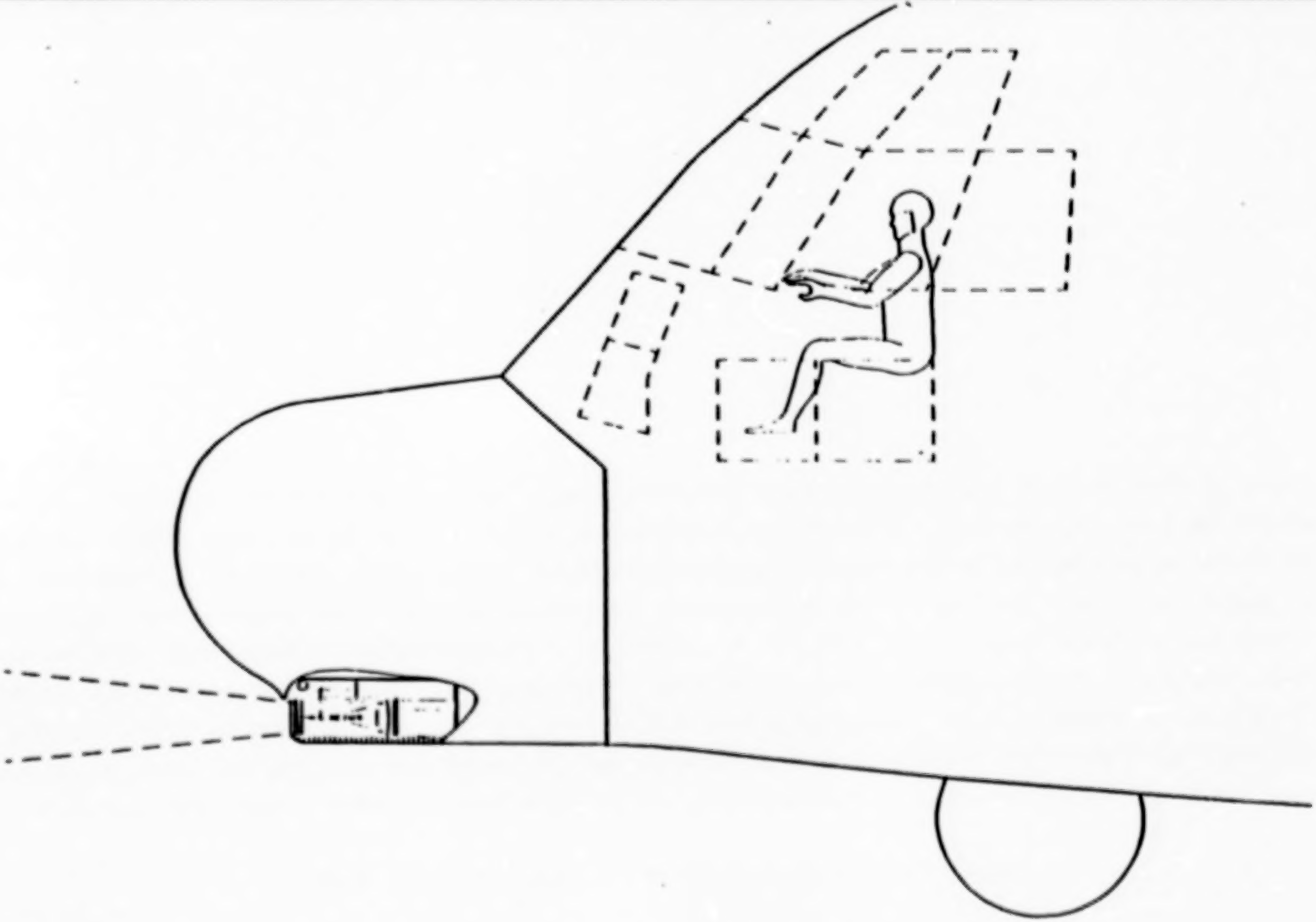
ALTOS BLOCK DIAGRAM USING PULSED LASER



ALTOS OPTICAL PAYLOAD



INTEGRATION OF ALTOS IN A C-130



SIGNAL-TO-NOISE RATIO FOR AN OPTICAL HETERODYNE SYSTEM

The received backscatter signal is proportional to the pulse energy transmitted by the laser, the backscatter cross section, and the square of the diameter of the collecting telescope. The received signal decreases as the square of the distance to the region observed. It also falls off as a function of atmospheric attenuation, fog, and rain. We have collected these factors and called them k(R), because they increase exponentially with range. In the calculation shown here, we are considering the case of clear air, i.e., no absorption. Attenuation due to fog and rain is described in the next pages. The noise power in a heterodyne receiver is proportional to the photon energy $h\nu$ times the system bandwidth B, all divided by the detection efficiency. Thus, in clear air the system described here will detect wind velocity with a signal-to-noise ratio of +35 dB at a range of 3 km, and +15 dB at 30 km.

BASIC SIGNAL-TO-NOISE RELATIONSHIP FOR LASER VELOCIMETRY

$$\boxed{\frac{S}{N} = \frac{\pi E d^2 \beta \lambda \eta K(R)}{8R^2 Bh}}$$

E	=	LASER PULSE ENERGY	2 mJ
d	=	TELESCOPE DIAMETER	0.15 m
β	=	BACKSCATTER CROSS SECTION	5×10^{-8} sr^{-1} m^{-1}
λ	=	LASER WAVELENGTH, 10.6 μm	10^{-5} m
η	=	DETECTION AND MIXING EFFICIENCY	0.1
$K(R)$	=	TOTAL EXTINCTION FOR RANGE R	
R	=	RANGE OF RETURN	30 km
B	=	DETECTOR BANDWIDTH	5×10^{5} Hz
h	=	PLANCK'S CONSTANT	7×10^{-34} Js

$\frac{S}{N}$ = 15 dB FOR CO_2 SYSTEM
IN CLEAR AIR

WIND SHEAR DISPLAY

One of a variety of possible wind-shear displays is shown in the illustration. In this example, the plane's heading is shown from the bottom to top of the instrument. It has numerical markers at 1, 2, and 3 km (or miles). There are five horizontal illuminated bars, one for each half km. The widths of these bars indicate the magnitude of the wind velocity (5, 10, 15, and 20 m/s). Arrows within the bars indicate the wind direction. The instrument does not require any attention from the flight crew, except when the ALTOS computer detects wind shear on the flight path. It would then sound an aural alert, and the pilot would observe the wind situation and make a decision. Crosswind is indicated on the instrument at the right.

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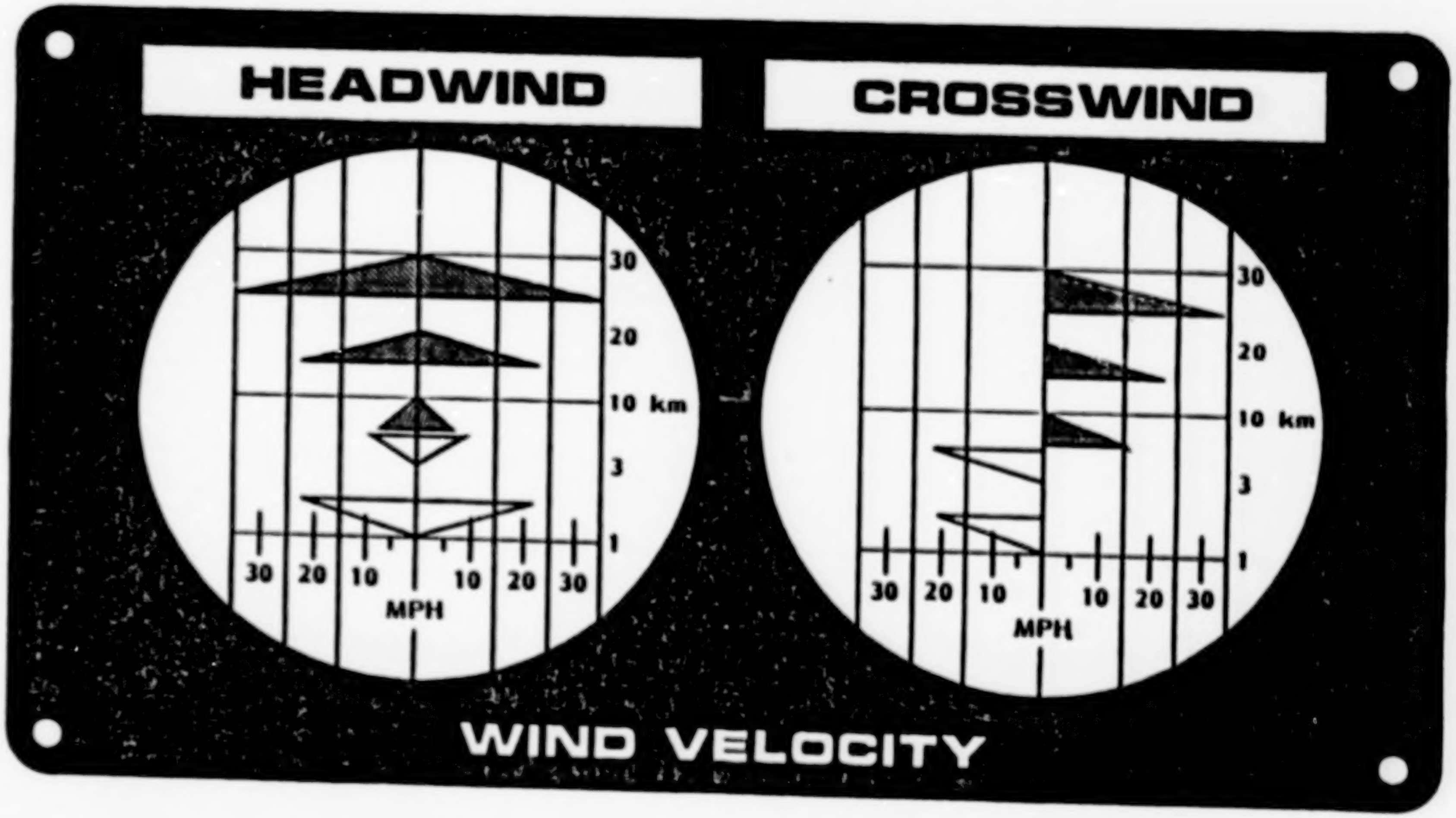
WIND VELOCITY DISPLAY.



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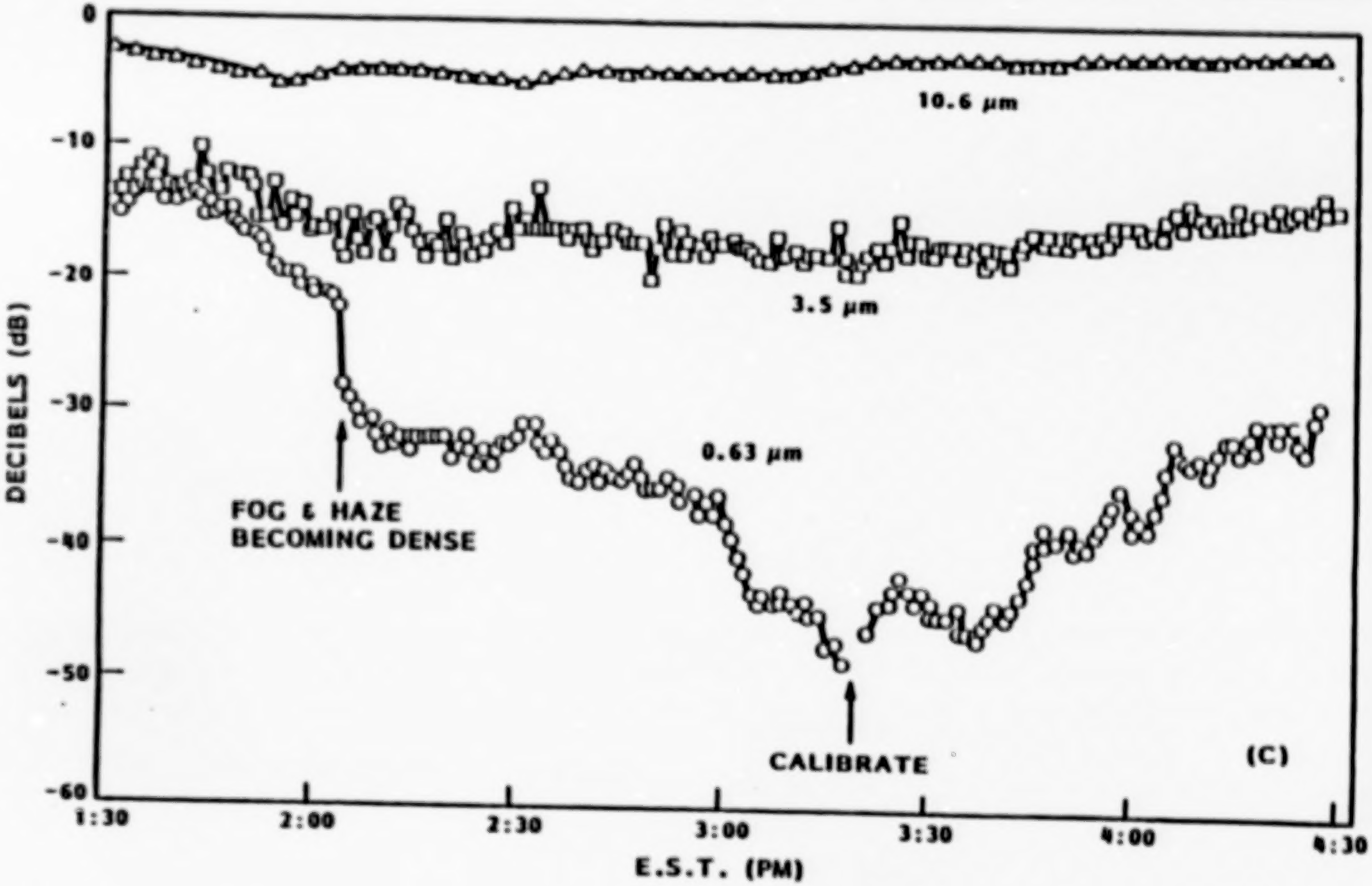
ALTERNATIVE WIND SHEAR DISPLAY

Wind velocities and directions at 1, 2, and 3 km are shown on a single instrument, along with the aircraft heading.

MEASUREMENT OF 2.6-km TRANSMISSION LOSS IN LIGHT FOG (0-dB SIGNAL LEVEL IN CLEAR WEATHER)

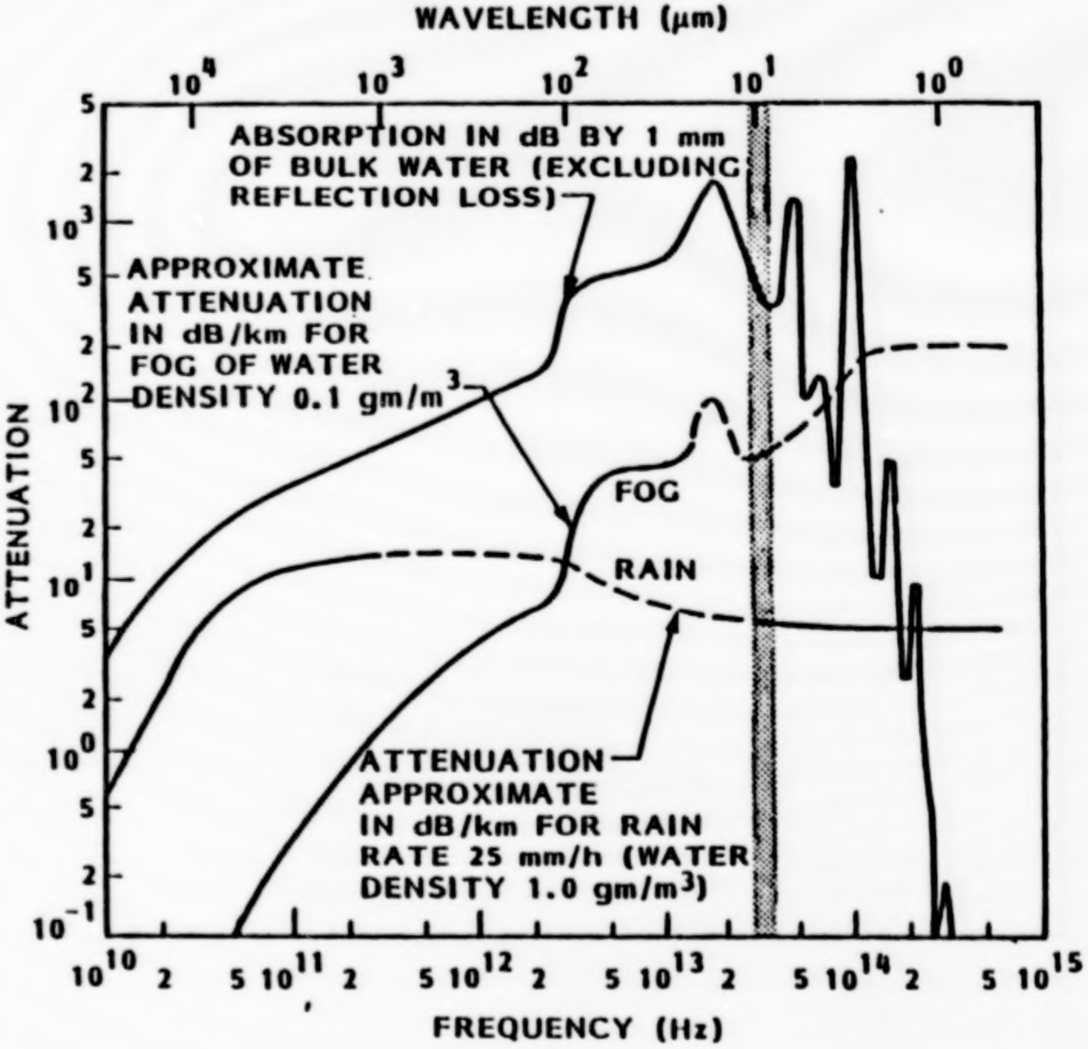


ATTENUATION DUE TO RAIN

The data in this figure show the attenuation due to rain and fog for signals across the electro-magnetic spectrum. Of particular interest is the attenuation for infrared radiation at 10.6 microns. At this wavelength, and a rain rate of 1-inch per hour, the attenuation is approximately 8 dB per km.

In the next figure we show attenuation for 10.6 microns as a function of rain rate, and the effect of rain on range and warning time.

EFFECTS OF PRECIPITATION ON PROPAGATION AT 0.63, 3.5, AND 10.6 MICRONS*

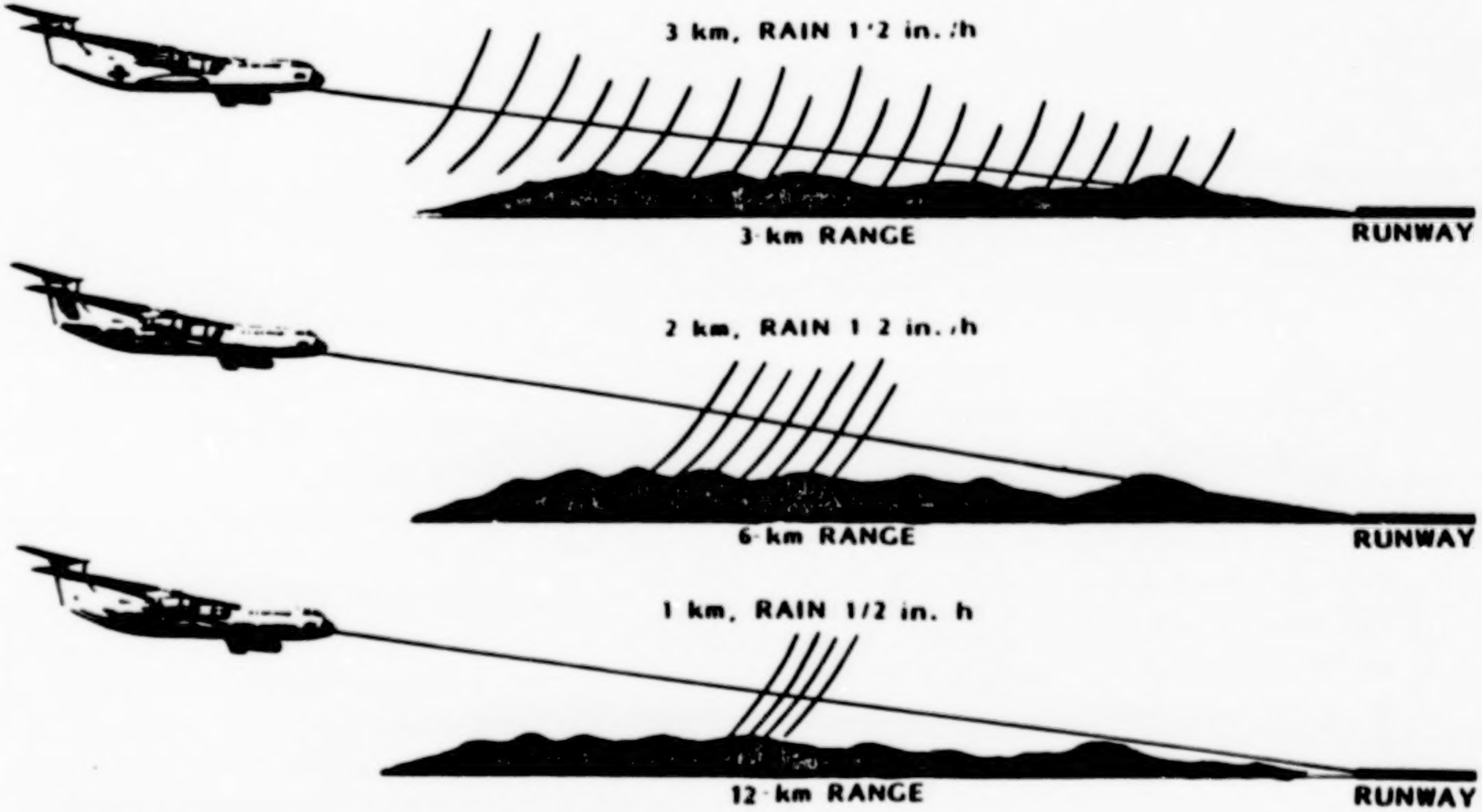


*BY T. S. CHU AND D. C. HOGG, BSTJ, MAY 1968

RANGE IN RAIN

The ALTOS wind shear detection system can measure wind velocities in the presence of rain, or an intervening rain cell. The illustration shows an aircraft using such a laser velocimeter as it approaches the runway. If the plane is 3-km away, it can penetrate the full 3 km of rain (1/2 inch/hour rate). If it is 6-km distant, it can penetrate a 2-km-thick rain cell. And at 12-km distance, it can still measure runway conditions through 1 km of intervening rain. Round trip attenuation due to rain is taken as 16 dB/km per inch of rain per hour.

RANGE IN RAIN



OPERATION IN AND THROUGH RAIN, WITH
MORE THAN 5 dB SIGNAL TO NOISE RATIO

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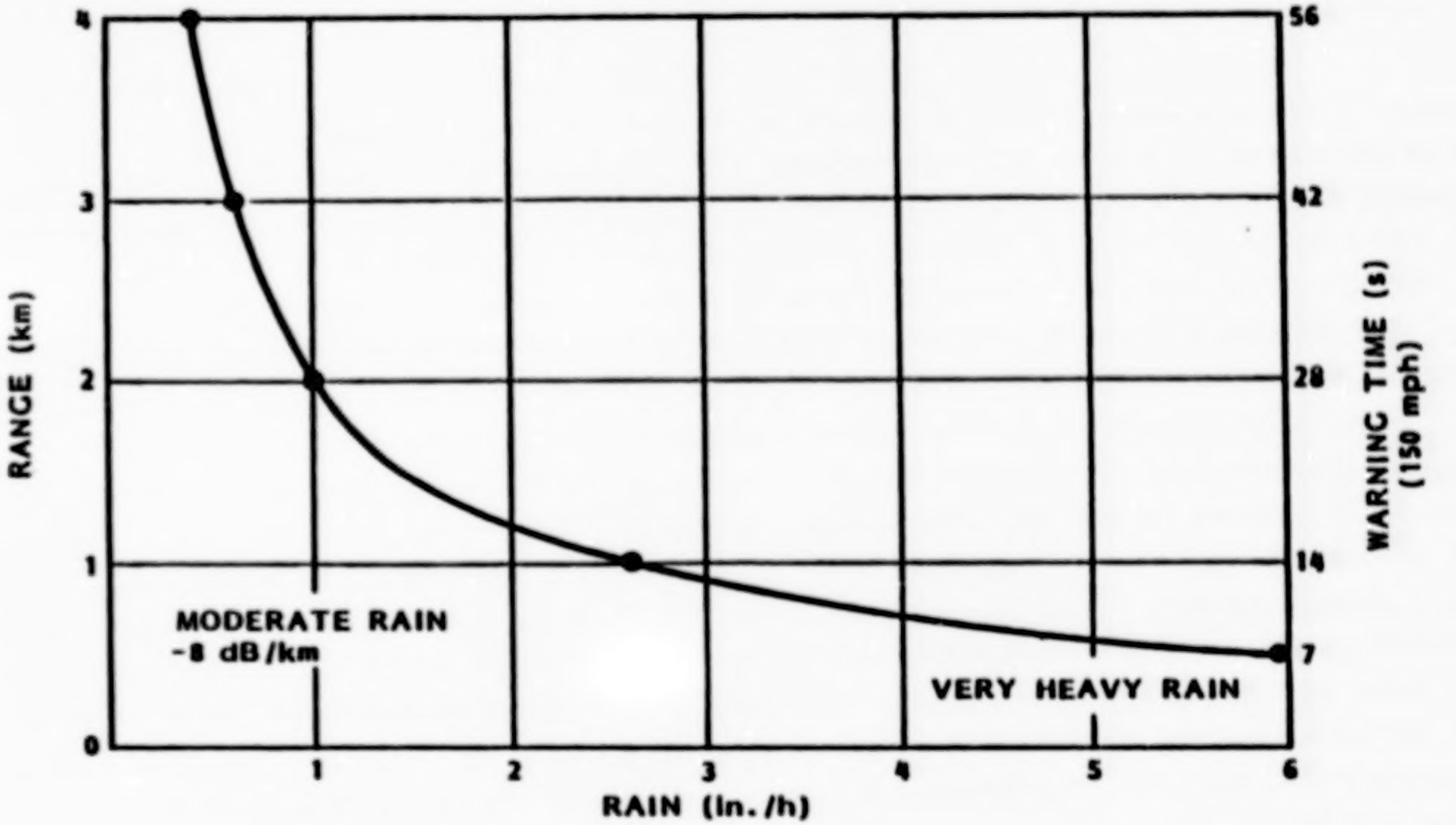
RANGE OF 10.6-MICRON SYSTEM IN RAIN

It is well known that the 10.6-micron radiation from CO_2 lasers is attenuated by rain, and that will limit the usefulness of such systems in conditions of heavy rain. A systems analysis of an integrated wind-shear detection and avoidance system will take into account the proven success of airborne weather radar to locate rain cells well in front of the aircraft, together with its relative inability to detect wind shear in clear air or in absence of rain. On the other hand, the figure shows the effects of rain on range, and indicates that a 50-mJ CO_2 lidar is able to penetrate rain of moderate levels for a sufficient distance to give a warning of 10 to 20 seconds to a pilot flying into a potentially dangerous situation. Thus it appears that a medium-power airborne weather or Doppler microwave radar working together with a similarly compact lidar system could make significant advances in detecting and avoiding the hazards of wind shear.

RANGE IN RAIN



DOPPLER LIDAR RANGE WITH $\frac{S}{N} = 5$ dB VERSUS RAIN

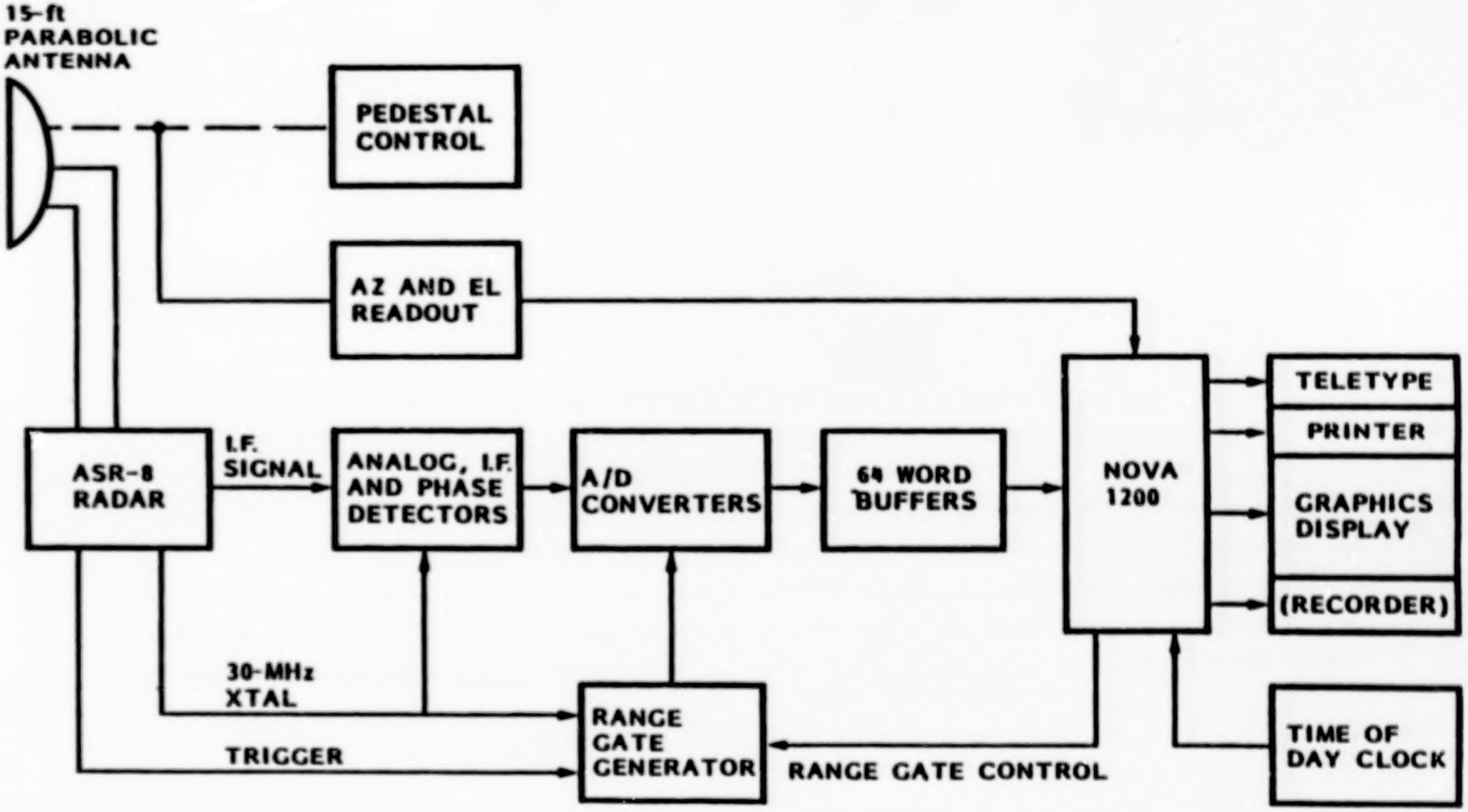
LASER ENERGY = 2 mJ AT 2000 Hz

TELESCOPE DIAMETER = 15 cm

MICROWAVE WIND VELOCITY MEASUREMENTS

High-power ground-based Doppler radars operating at C-band and X-band are able to measure wind velocity of 10- to 20-km distance by measuring the scattered radiation primarily from precipitation, ice crystals, or other debris in the air. A dual-Doppler microwave system could be deployed in which the radial wind components measured by each radar are combined, and the total wind field in the approach area can be specified. If the wind data for the flight paths could be rapidly updated and made available to the pilots, flight safety could be greatly improved. A major problem with on-airport radars — and to an even greater extent airborne radars — is the appearance of ground clutter. For the airborne system, the clutter return from the moving terrain along the flight path has a much greater amplitude, and a frequency in the same band, as the hoped-for Doppler return from aerosols in the wind. In comparing airborne radars with the ground-based systems such as those participating in the successful JAWS measurements, one must take into account the reduction in transmitter power that such a system will have available, as well as the reduced antenna aperture of the airborne system, leading to a beam divergence of several degrees. All these factors can have a significant impact on the ultimate achievable signal-to-noise ratio (-30 to -40 dB as compared with a ground-based system). Another consideration is that microwave systems receive only minimal returns from dry air. Although in the Southern United States wind shear is usually associated with violent thunder storms, in the Denver study (JAWS), 80 percent of the observed wind-shear events were dry at ground level.

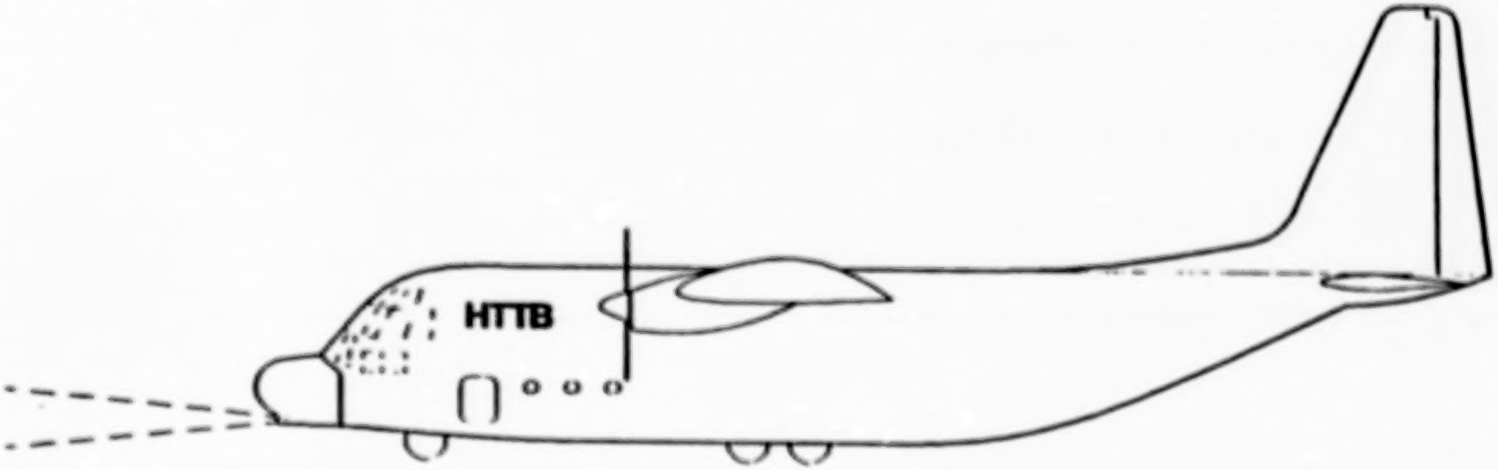
BLOCK DIAGRAM OF NATIONAL AVIATION FACILITIES EXPERIMENTAL CENTER (NAFEC) RADAR WIND-SHEAR-DETECTION SYSTEM



LOCKHEED HIGH TECHNOLOGY TESTBED

The Lockheed Georgia Corporation has modified one of their production C-130 transport planes to make it a Lockheed facility and testbed for the airborne evaluation of avionic systems. In cooperation with their engineering staff, we plan to flight test the ALTOS wind-shear avoidance system brassboard on the HTTB. An avionics pod, 4 feet in diameter and 21-feet long, is available for the installation of this equipment. The pod has independent power, and is connected to the main flight instruments by a video-bandwidth optical data link.

INTEGRATION OF ALTOS IN A C-130



CONCLUSIONS AND RECOMMENDATIONS

- NEAR-TERM CAPABILITY EXISTS TO PERFORM AIRBORNE, FORWARD-LOOKING, THREE-DIMENSIONAL, WIND VELOCITY MAPPING FOR WIND SHEAR DETECTION AND AVOIDANCE
  - FLYING LIDAR TECHNOLOGY EXISTS
  - AVIONICS PACKAGING AND COMPONENT SELECTION FOR SPECIFIC APPLICATION NEED TO BE DONE
  - PRODUCTION PROTOTYPE TO BE PRECEDED BY BRASSBOARD FLIGHT PROGRAM
- RECOMMEND BRASSBOARD FLIGHT DEMONSTRATION PROGRAM
  - PHASE I: DESIGN THROUGH PRELIMINARY DESIGN REVIEW – 6 MONTHS
  - PHASE II: FINAL DESIGN AND FABRICATION – 12 MONTHS
  - PHASE III: INTEGRATION AND FLIGHT TEST – 9 MONTHS

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CO_2 LASER TECHNOLOGY FOR WIND SHEAR DETECTION

J. J. Ewing & S. Byron
Spectra Tech

Spectra Technology

CO_2 LASER TECHNOLOGY FOR AIRBORNE LIDAR WIND SHEAR DETECTION

Prepared For

Wind Shear Workshop
NASA Langley Research Center

by

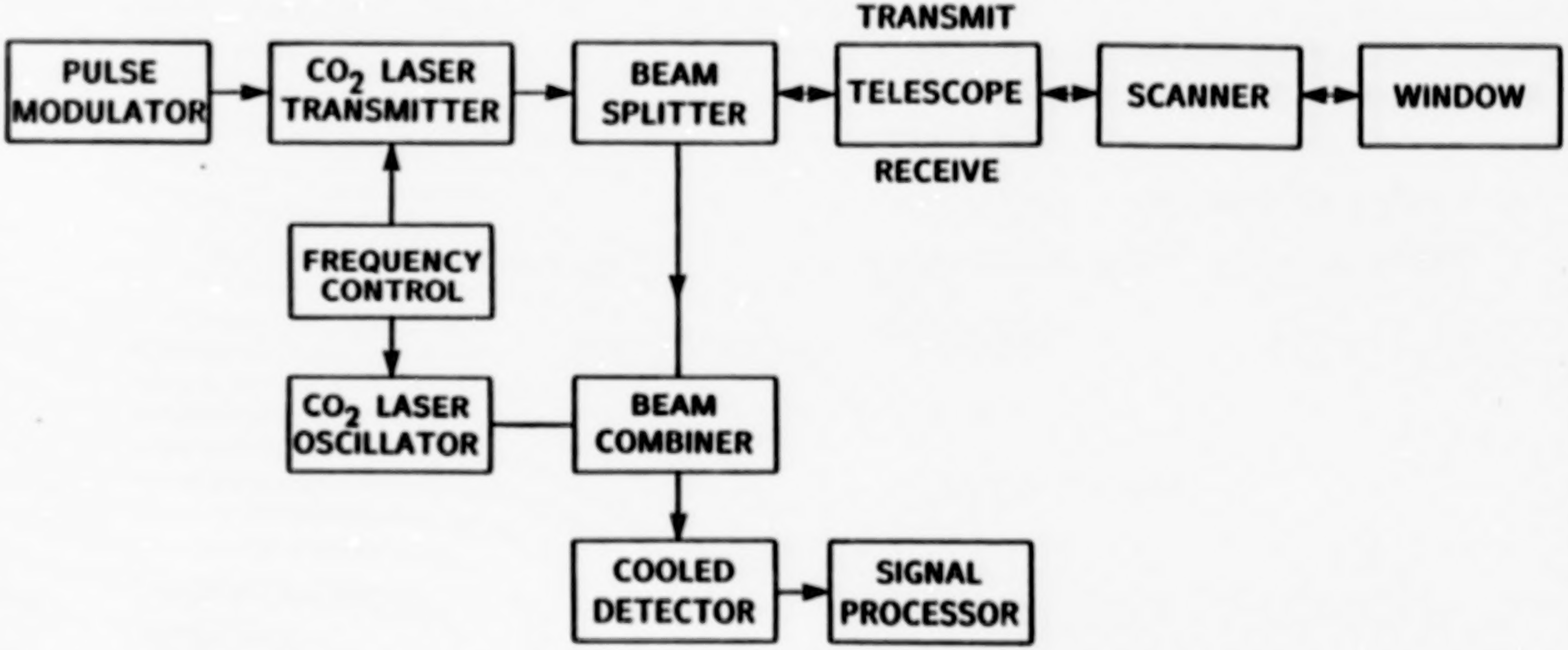
Stan Byron, Steve Moody, and J.J. Ewing
Spectra Technology, Inc.

24 February 1987

CO_2 LASER SYSTEM OBJECTIVES

Direction:	Forward Looking
Range:	>3 km
Range Resolution:	<0.3 km
Wind Velocity Resolution:	<2 m/sec Along Flight Direction <8 m/sec Transverse to Flight
Wind Field Up-Date Interval:	<1.0 sec
Weather:	Clear Air to Heavy Rain
Size:	<0.1 m^3
Power Input:	<300 W
Cost:	<$100.000

CO_2 LASER FUNCTIONAL BLOCK DIAGRAM



PULSE MODULATOR

CO_2 LASER TRANSMITTER

BEAM SPLITTER

TRANSMIT

TELESCOPE

RECEIVE

SCANNER

WINDOW

FREQUENCY CONTROL

CO_2 LASER OSCILLATOR

BEAM COMBINER

COOLED DETECTOR

SIGNAL PROCESSOR

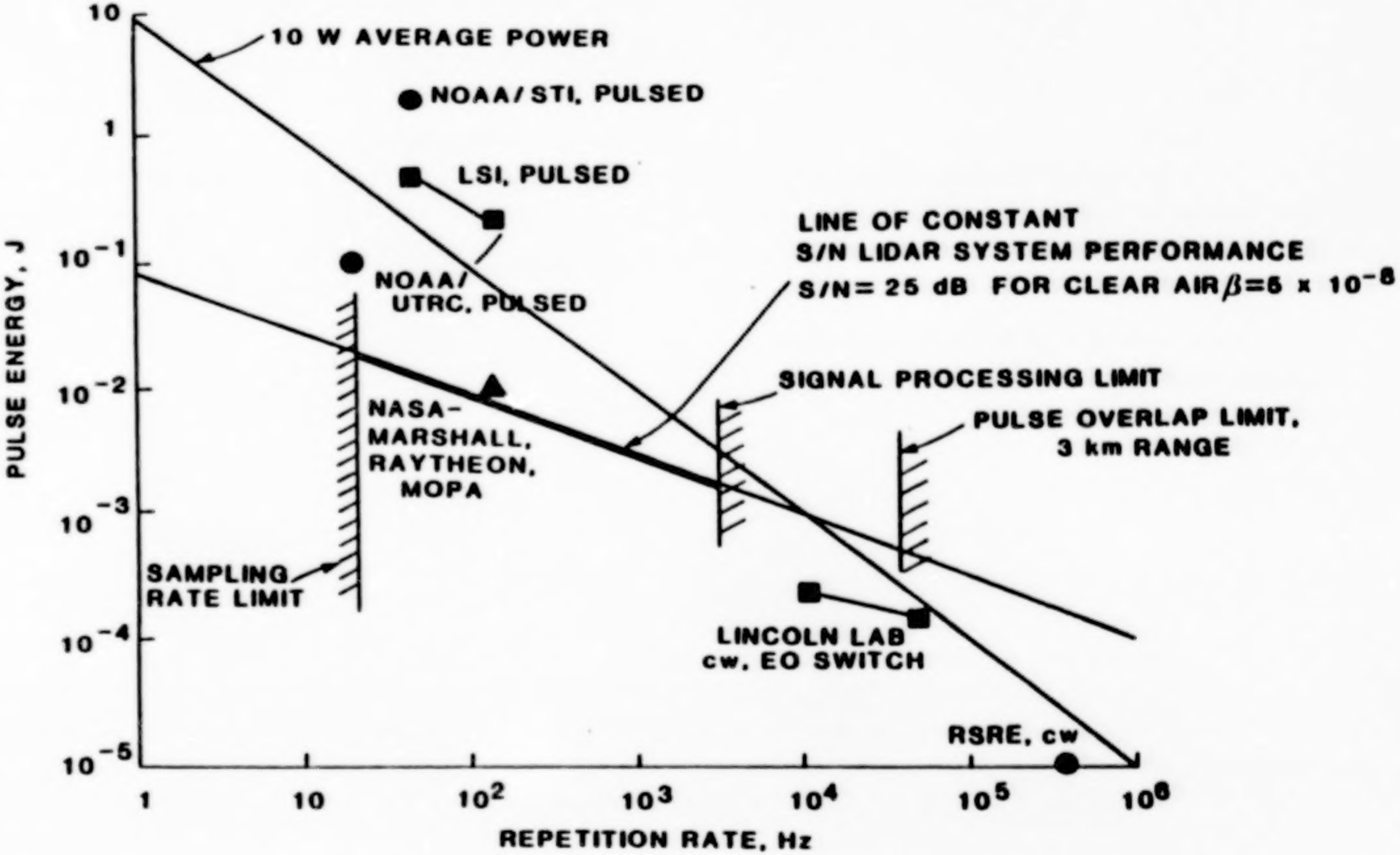
CO_2 LASER TECHNICAL REQUIREMENTS

FUNCTION	REQUIREMENTS	OBJECTIVES
Optical Output	Pulsed	Weather, Range
Scan Capability	0, 7°, 15° off axis 8 directions	Turns, Transverse Wind
Sampling	>20 Hz	Up-Date Interval
Frequency Stability	<200 kHz	Velocity Resolution
Chirp Limit	<200 kHz	Velocity Resolution
Pulse Tail	$<10^{-8}$ W after 6 μsec	Range Resolution

ALTERNATIVE CO_2 LASER APPROACHES

	Peak Power Range, W
cw EXCITATION	
cw Optical Output	10
Internal Cavity EO Modulation	10^3
PULSED EXCITATION	
Master Oscillator Power Amplifier	10^3
Gain Switched Oscillator	10^6

PERFORMANCE MAP OF CO_2 COHERENT LASERS FOR WIND SHEAR DETECTION



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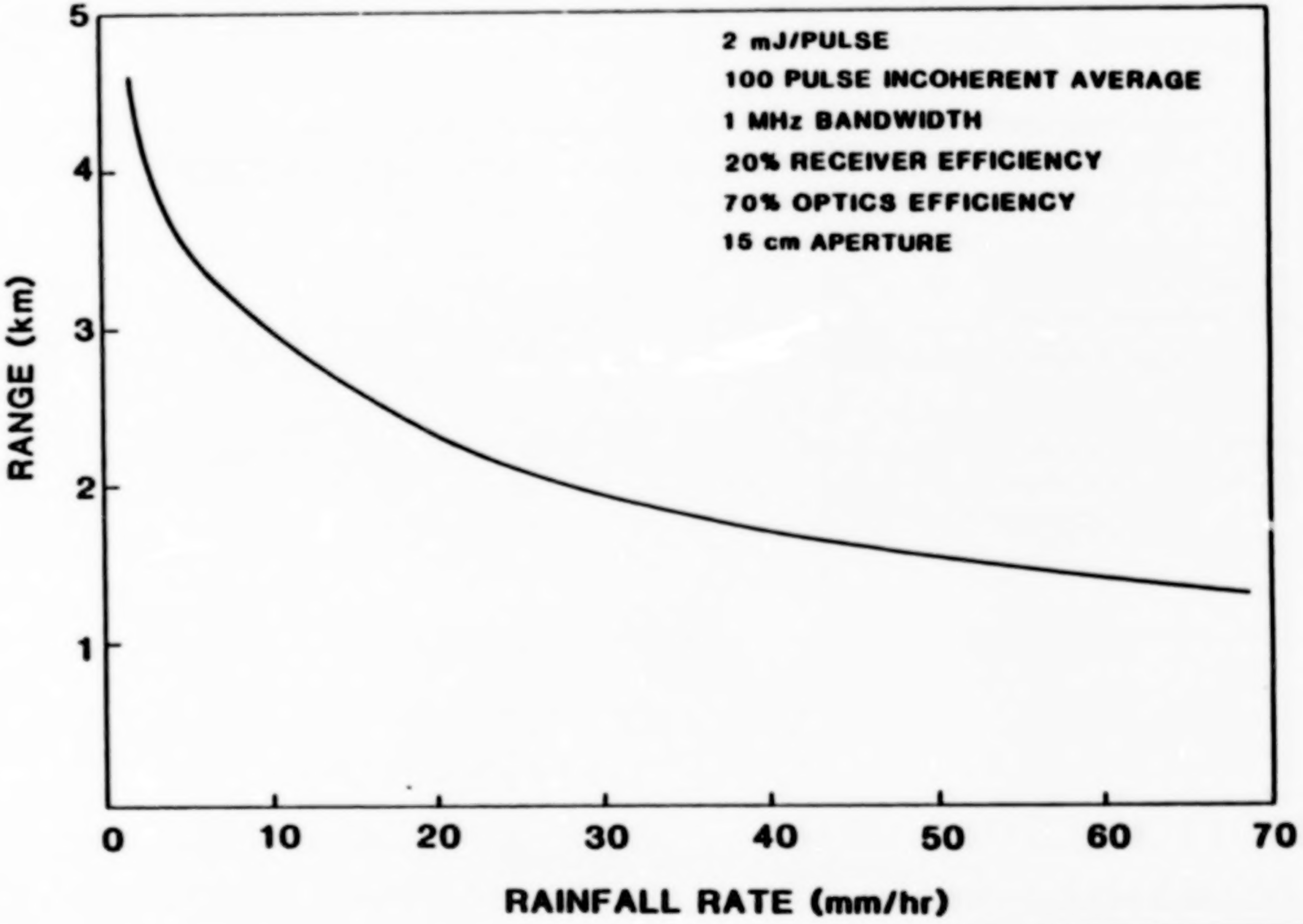
Spectra Technology

PREDICTED LIDAR RANGE IN RAIN



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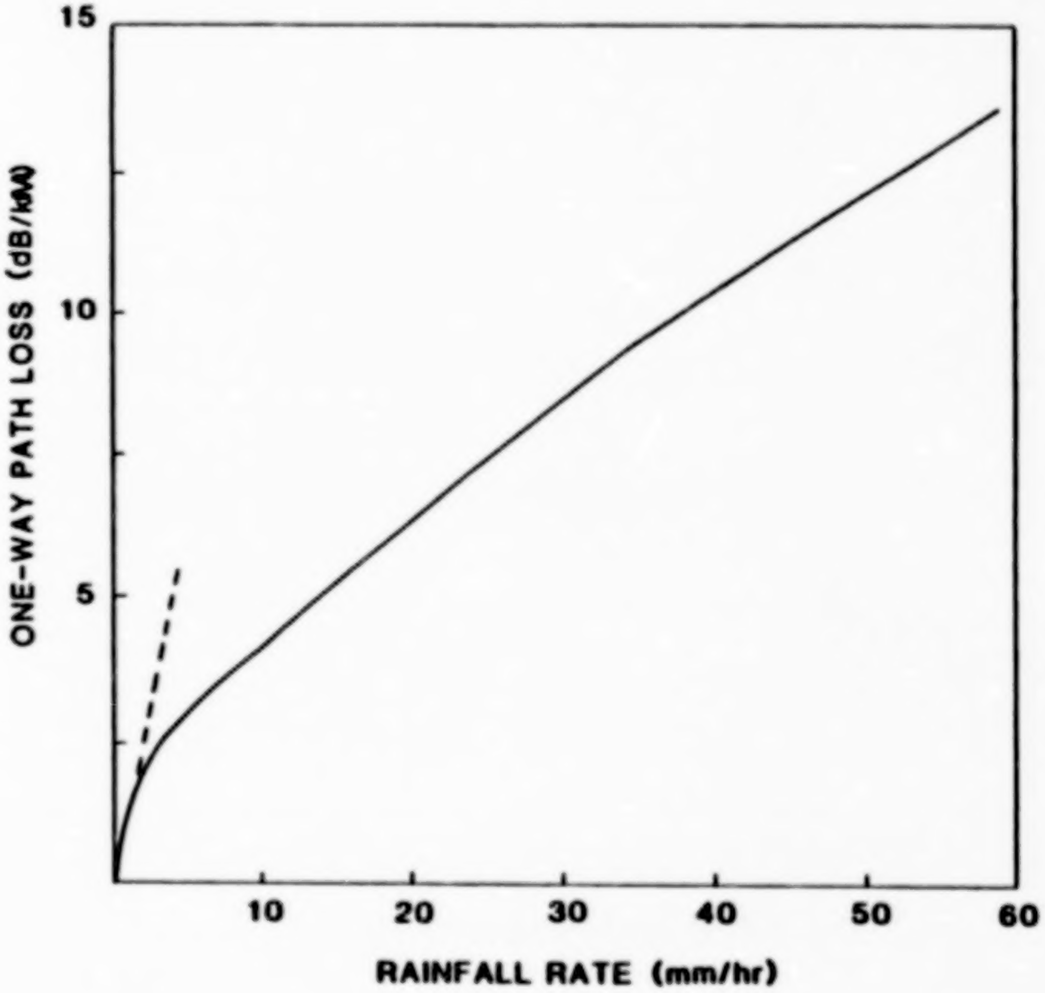
Spectra Technology

ASSUMED DEPENDENCE OF ATTENUATION WITH RAINFALL



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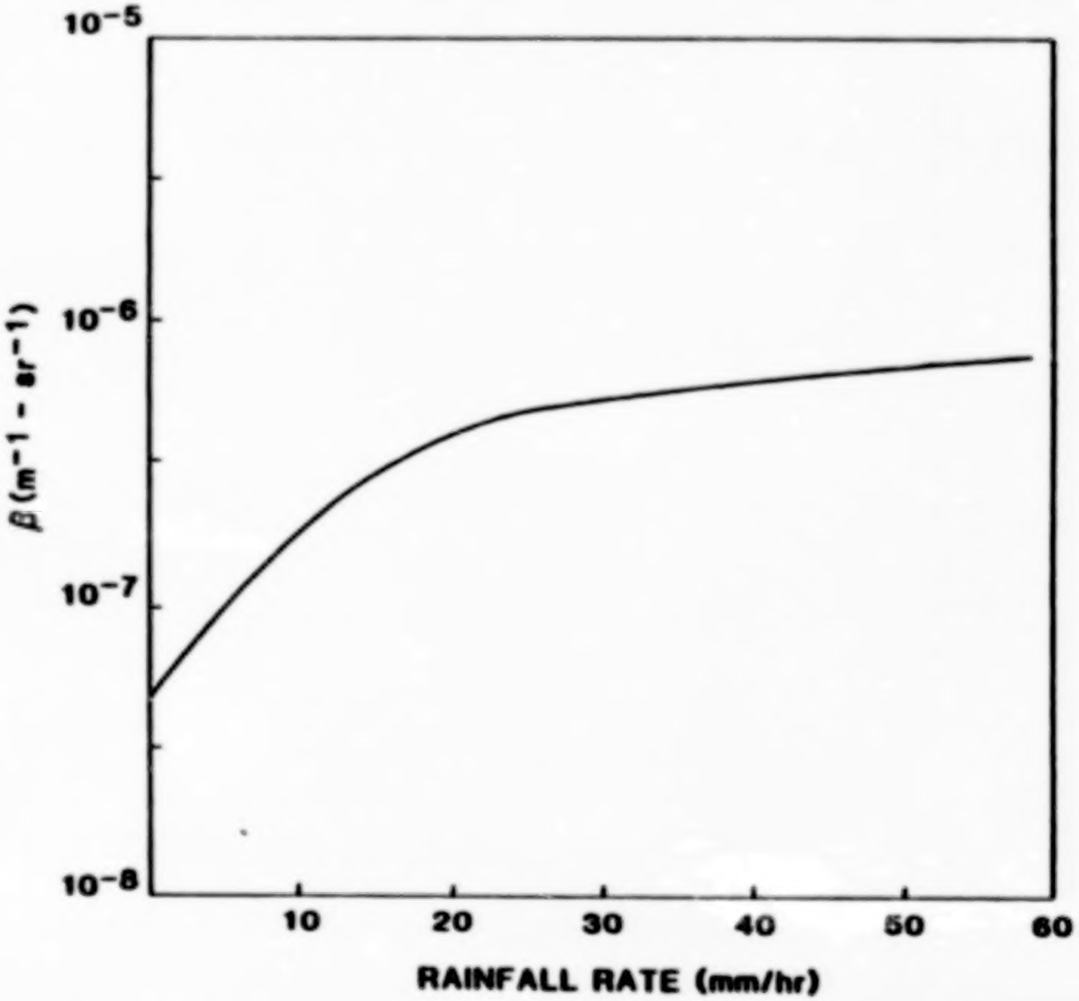
Spectra Technology

ASSUMED DEPENDENCE OF β WITH RAINFALL



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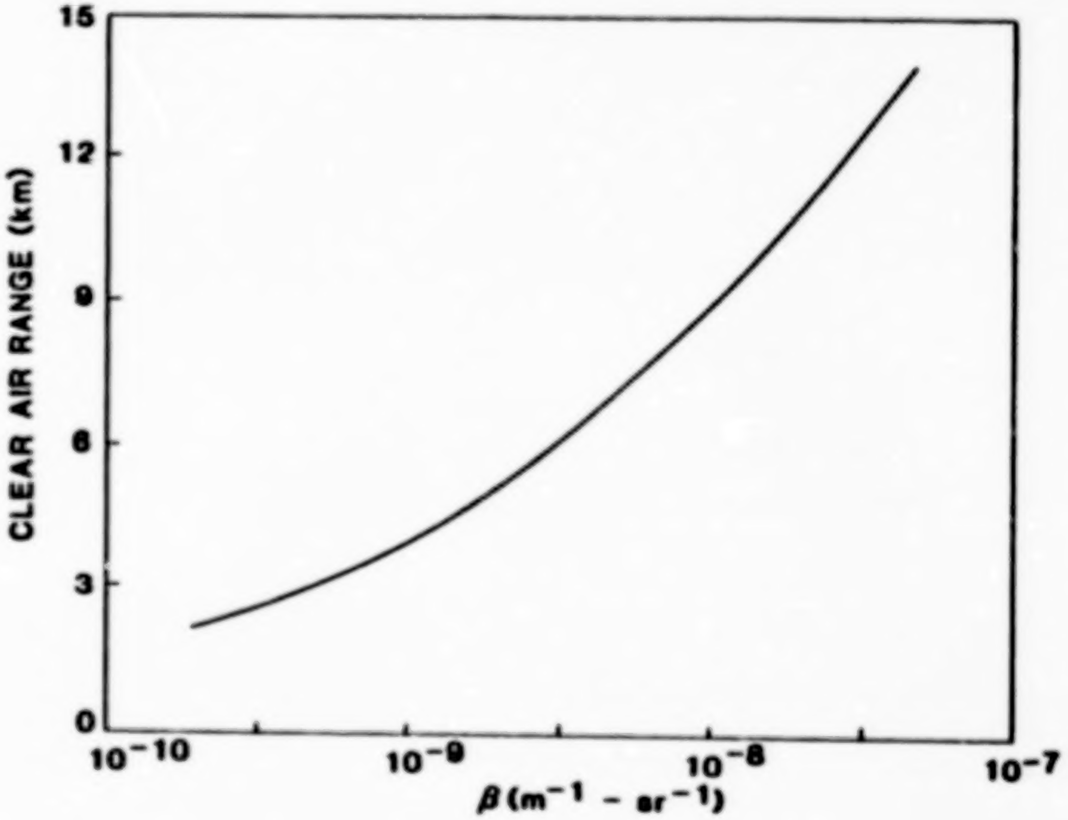
CLEAR AIR PERFORMANCE vs BACKSCATTER



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Spectra Technology

CO_2 LASER TECHNOLOGY SELECTION ISSUES

COMMON ISSUES

- Frequency Stability in Flight
- All Weather Performance
- Compact Size
- System Maintenance
- Cost

PULSE EXCITED LASERS

- Frequency Chirp
- Pulse Tail Quenching
- Sealed Tube Life
- Switch Life
- Electromagnetic Interference

cw EXCITED LASERS

- Electro-optic Modulation
- Pulse Duration
- Pulse Energy
- Signal Processing

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CONCLUSIONS

- CO_2 laser technology is well suited to meet requirements for airborne equipment to give advance warning of wind shear conditions

- Effective CO_2 laser performance parameter regime has been identified: 20 mJ, 20 Hz to 2 mJ, 2 kHz

- Current CO_2 wind measuring equipment is too sophisticated, too large, and too costly

- A moderate development effort will provide prototype lasers suitable for application to commercial airplane operation

LIDAR MEASURING CONCEPT

R. M. Huffaker
Coherent Technologies

COHERENT TECHNOLOGIES, INC.

R. MILTON HUFFAKER

NASA/FAA - WIND SHEAR BRIEFING

LIDAR MEASURING CONCEPT

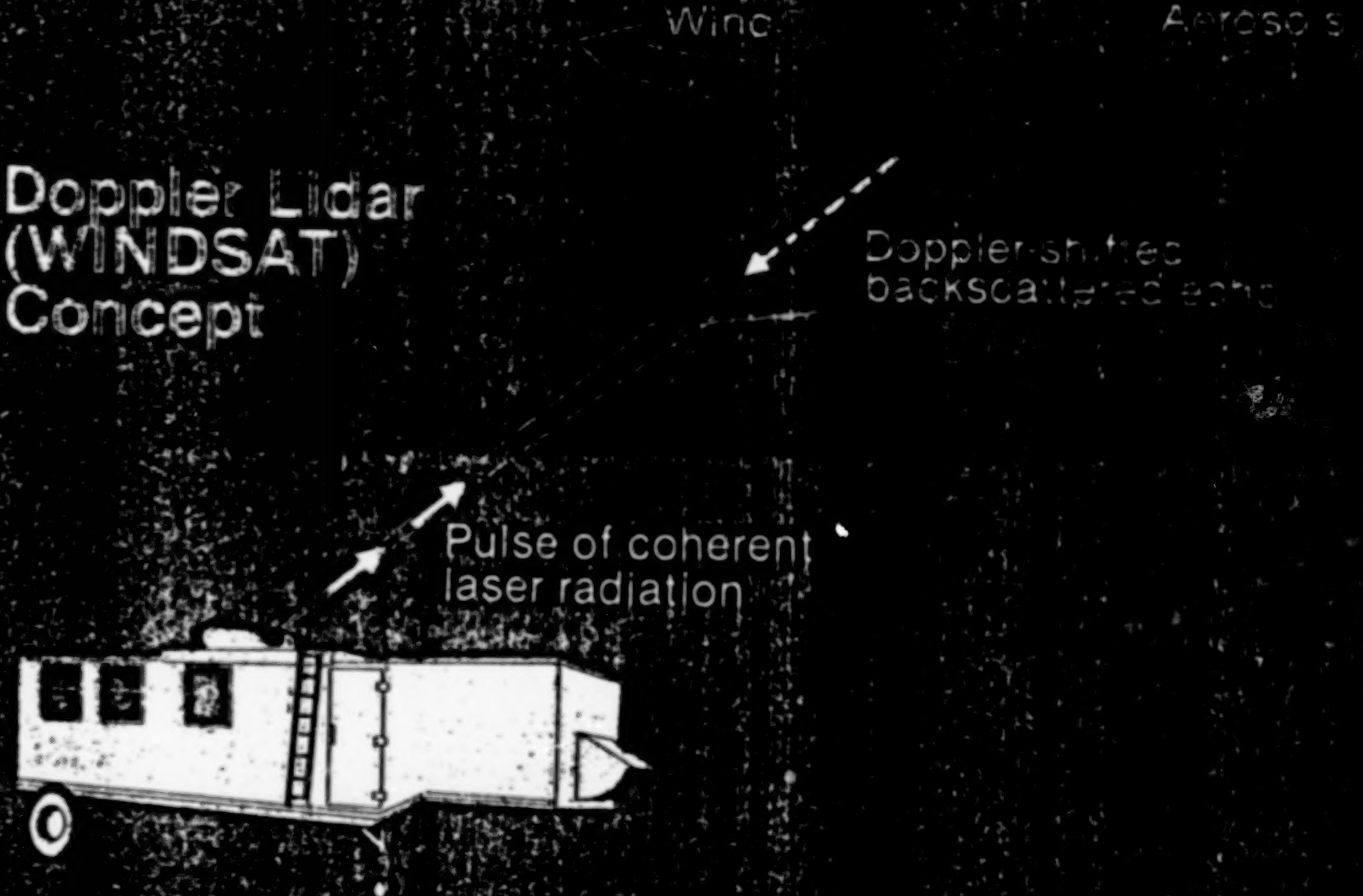
PAST STUDIES AND MEASUREMENTS

CURRENT TECHNOLOGY, CO_2 - SOLID-STATE

KEY ASPECTS OF A DOPPLER LIDAR WIND SHEAR PROGRAM

RECOMMENDATIONS

Doppler Lidar (WINDSAT) Concept



Wind

Aerosols

Doppler-shifted backscattered echo

Pulse of coherent laser radiation

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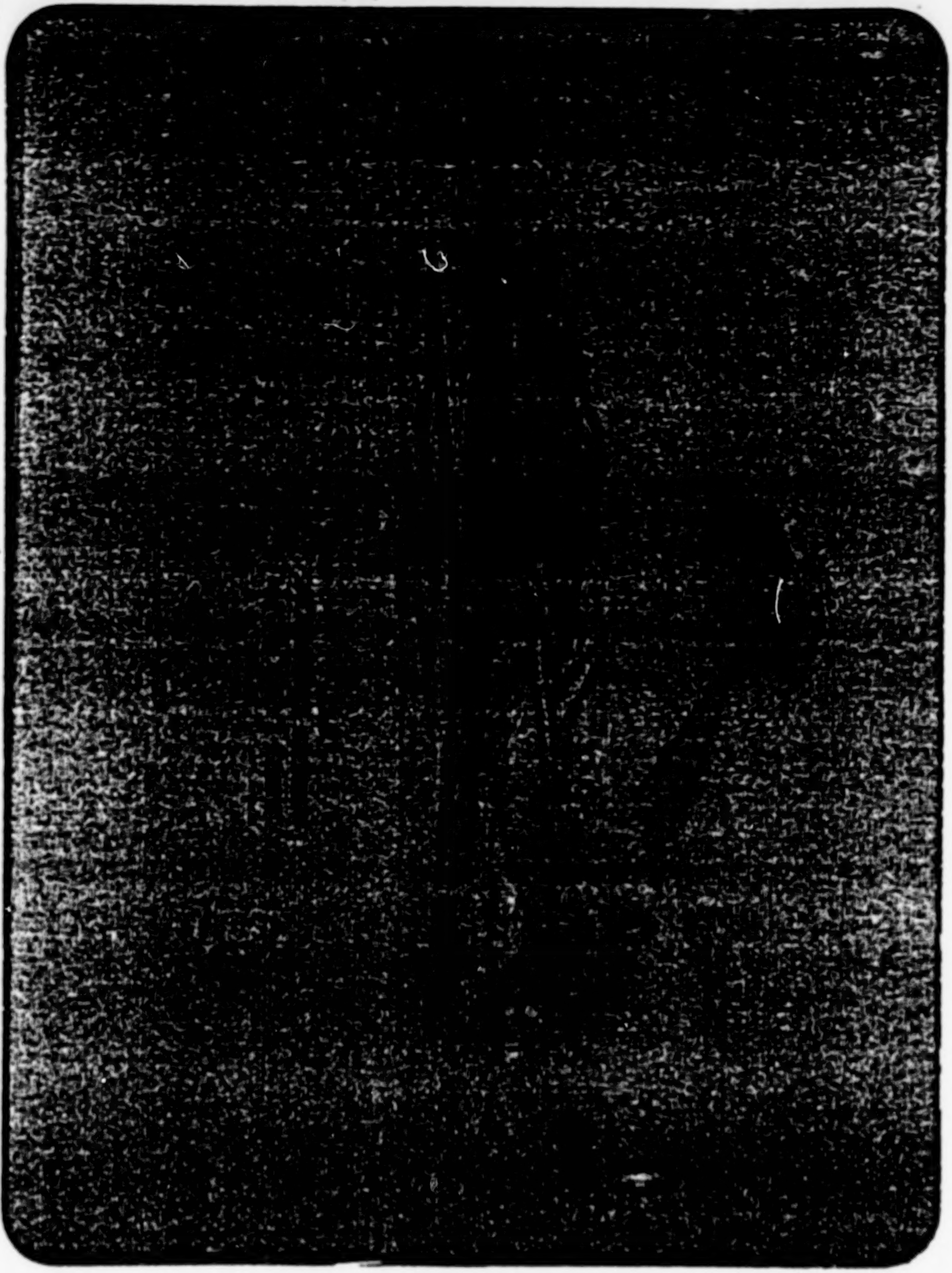

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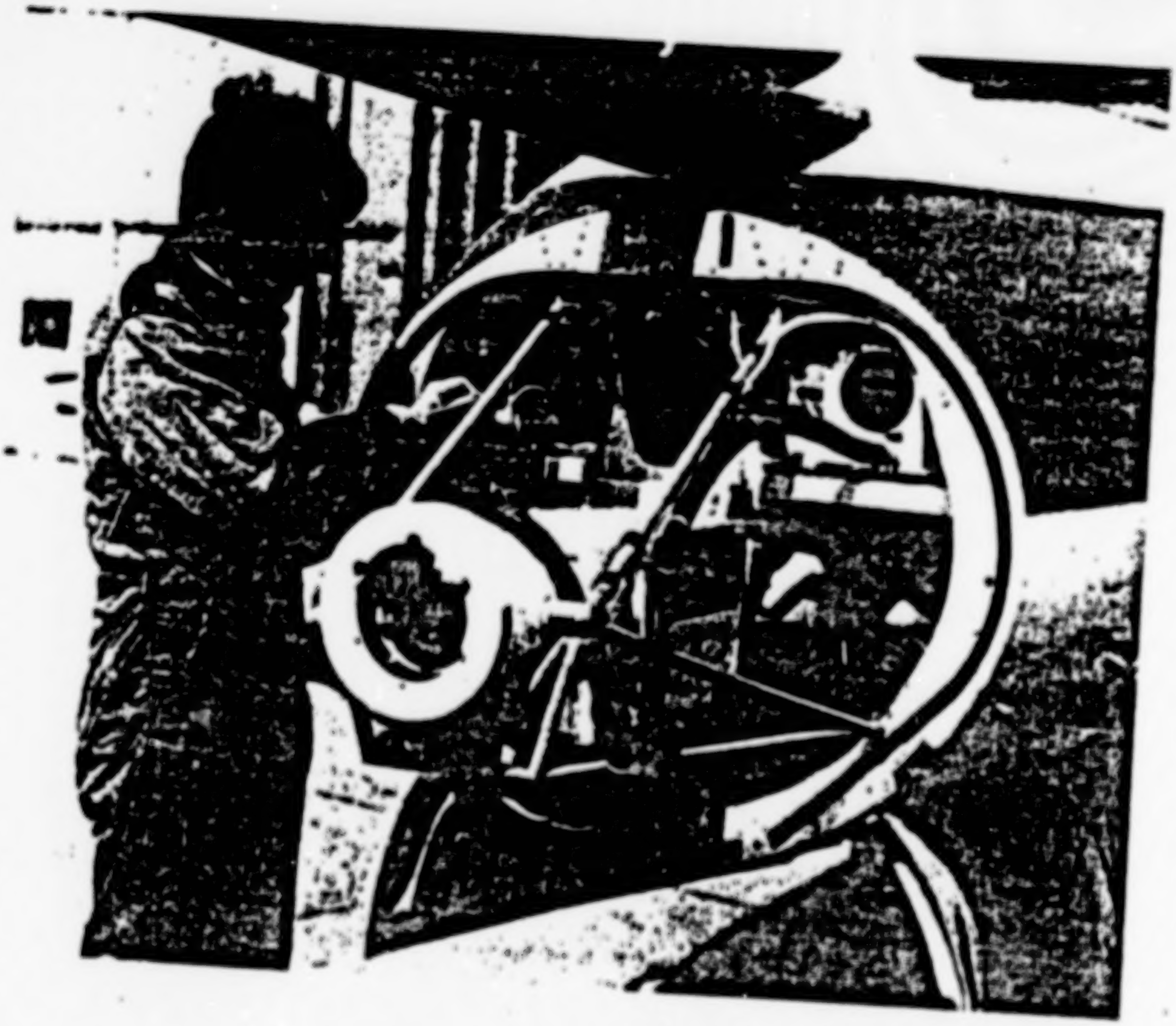
LASER WIND SHEAR DETECTORS

RAE and the Royal Signals and Radar Establishment have developed and tested laser airspeed measuring systems for remote sensing in both ground and airborne installations, using CW focussed beams.

Experimental ground based system had a useful maximum range of 1 km. Studies of a system to provide total airport wind information out to 6 km, or more, are in hand.



LAser True Airspeed System (LATAS) is a compact experimental system which identifies wind changes about 3 seconds before they reach the aircraft (HS 125). The LATAS laser is totally safe for general use, as its beam is invisible infra-red light.

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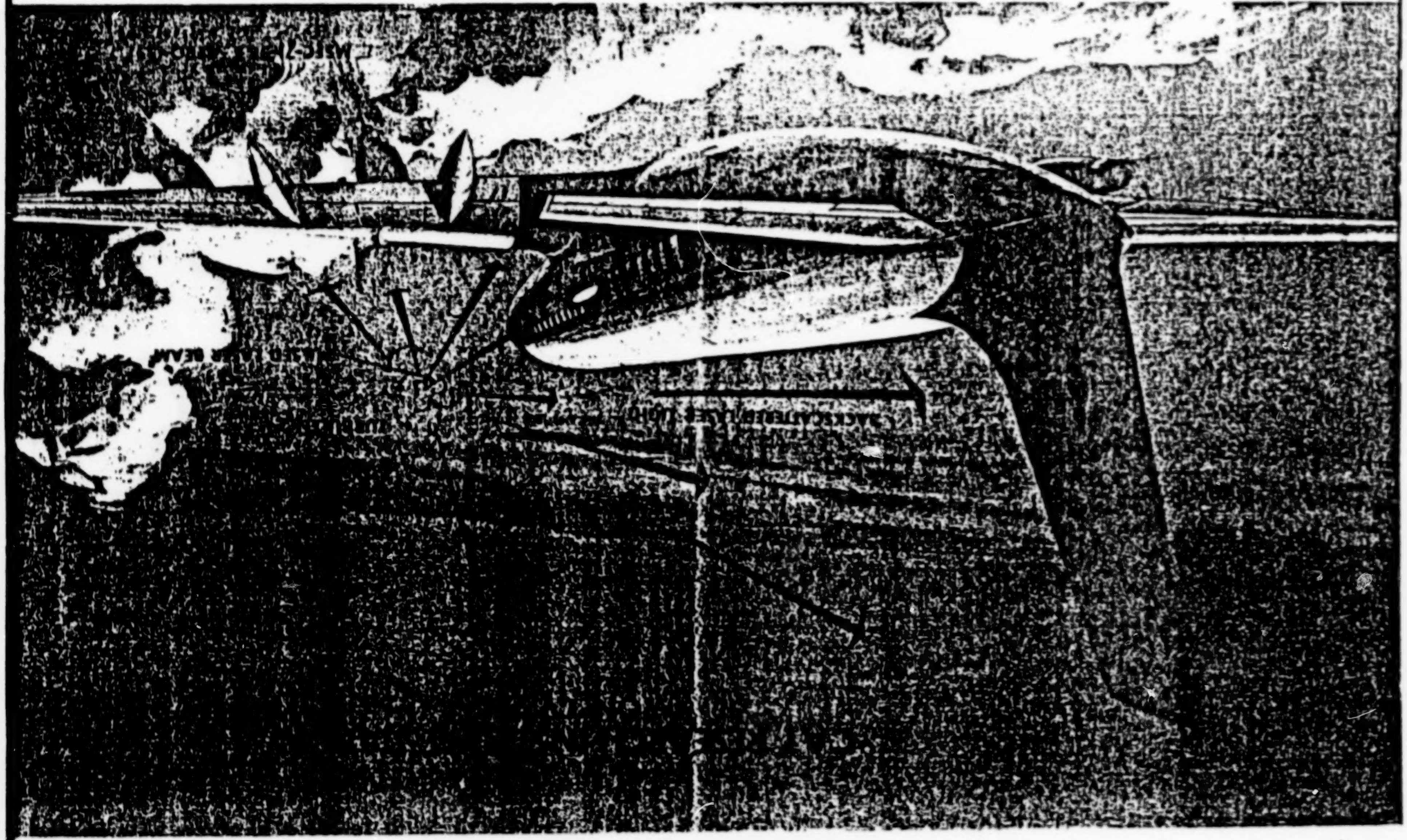
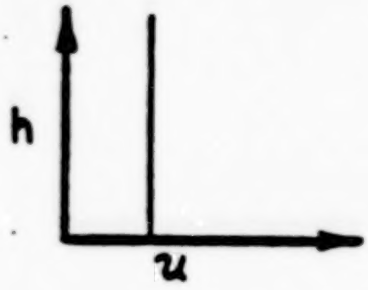
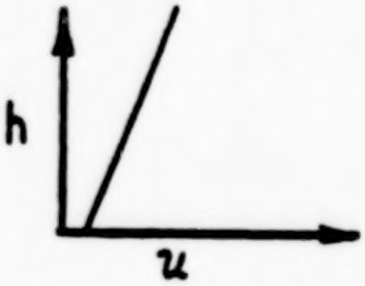


WIND MODELS

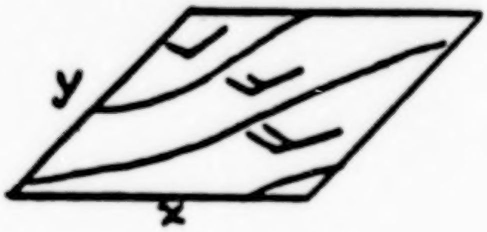
CONSTANT 1 M/S (0D)



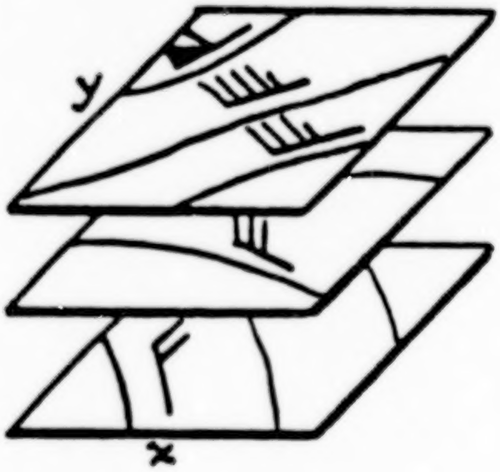
SHEAR WITH HEIGHT (1D)



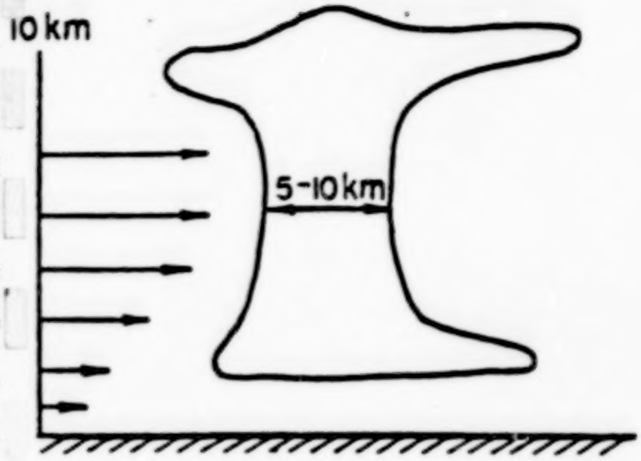
COHERENT u, v STREAMS (2D)

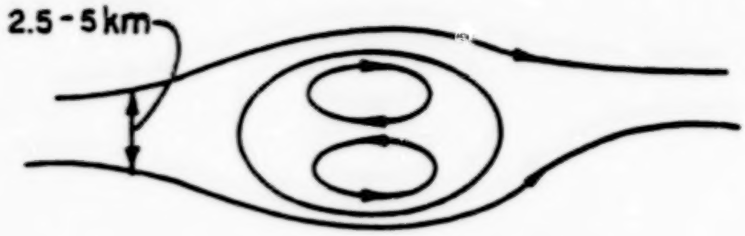


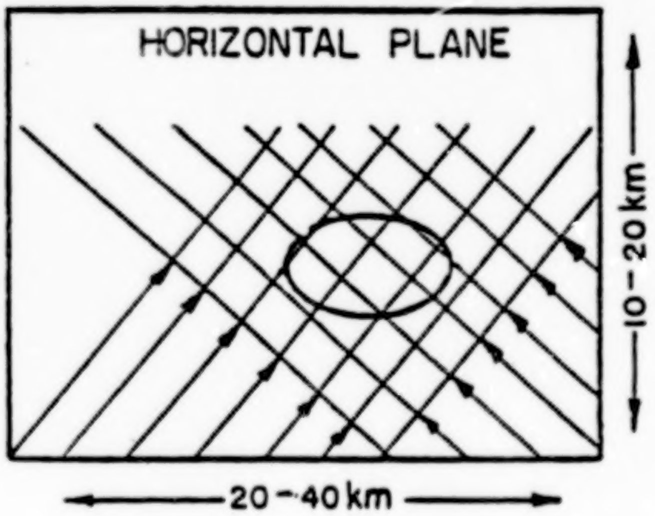
SHEAR WITH u, v STREAMS (3D)



Visual Products Division 3M
CATALOG NO. 15-1006-4
MADE IN U.S.A.





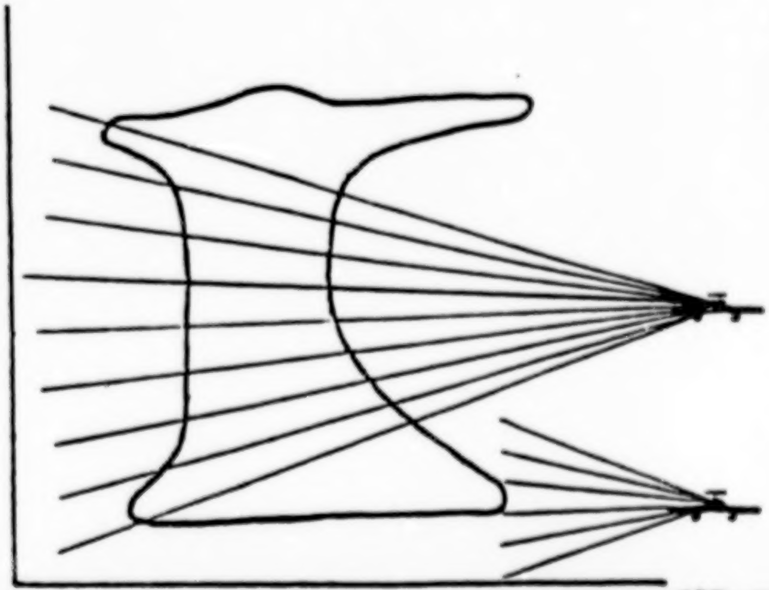


2 Position LOS with Vertical Scan

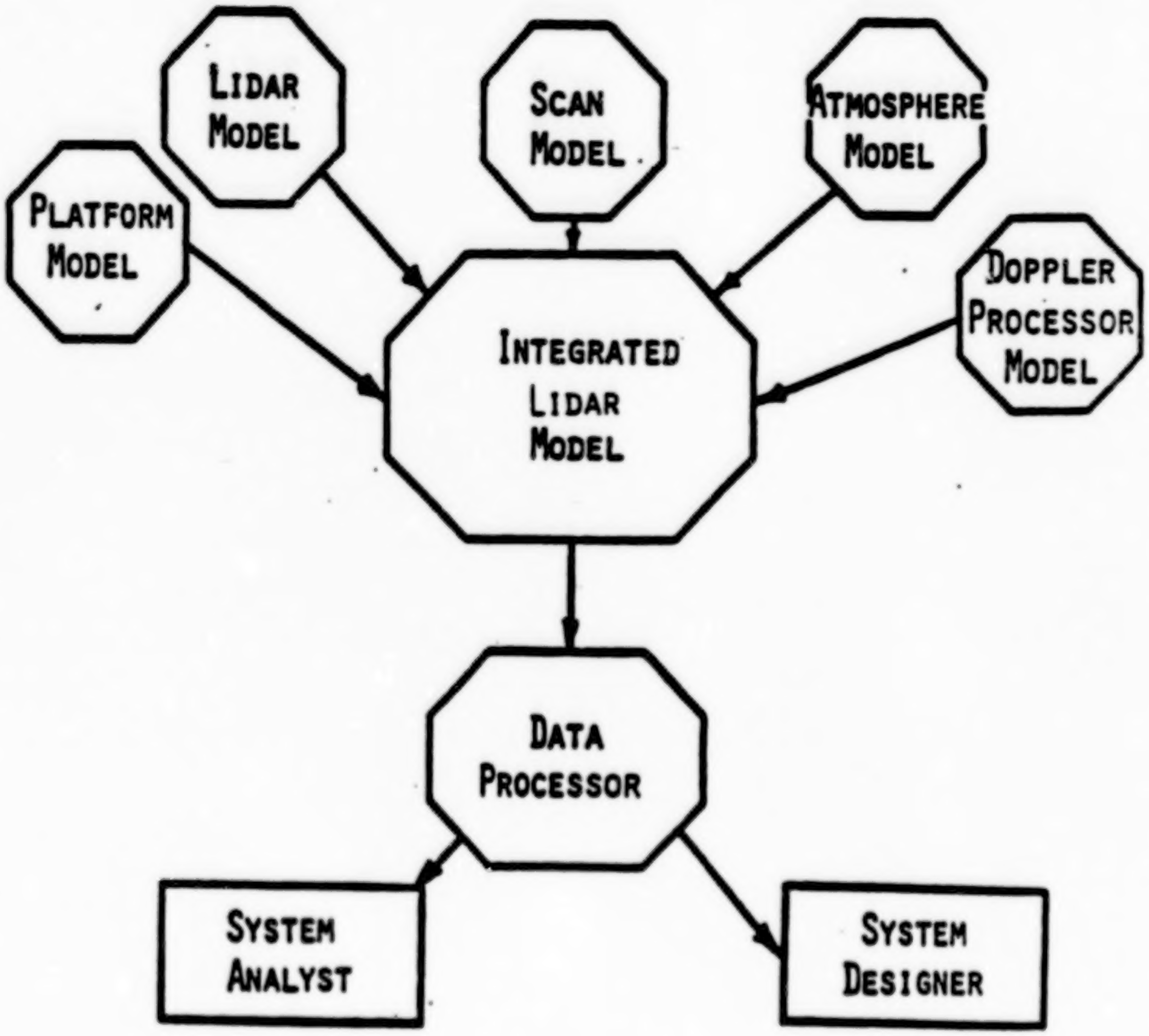
- Measurement (Frame) Time:
  4 - 8 min (100m/sec)
- Δx = 300m (60×60 grid)
- 18 data/sec/plane
  (10 vertical planes ⇒ 180 data/sec)
- 1 vertical scan/6 seconds

Measure:

- $u(x,y,z)$, $v(x,y,z)$
- spectrum with (turbulence)
  no x,y,z



GROUND-AIRBORNE-SATELLITE LIDAR COMPUTER SIMULATION



COHERENT TECHNOLOGIES, INC.

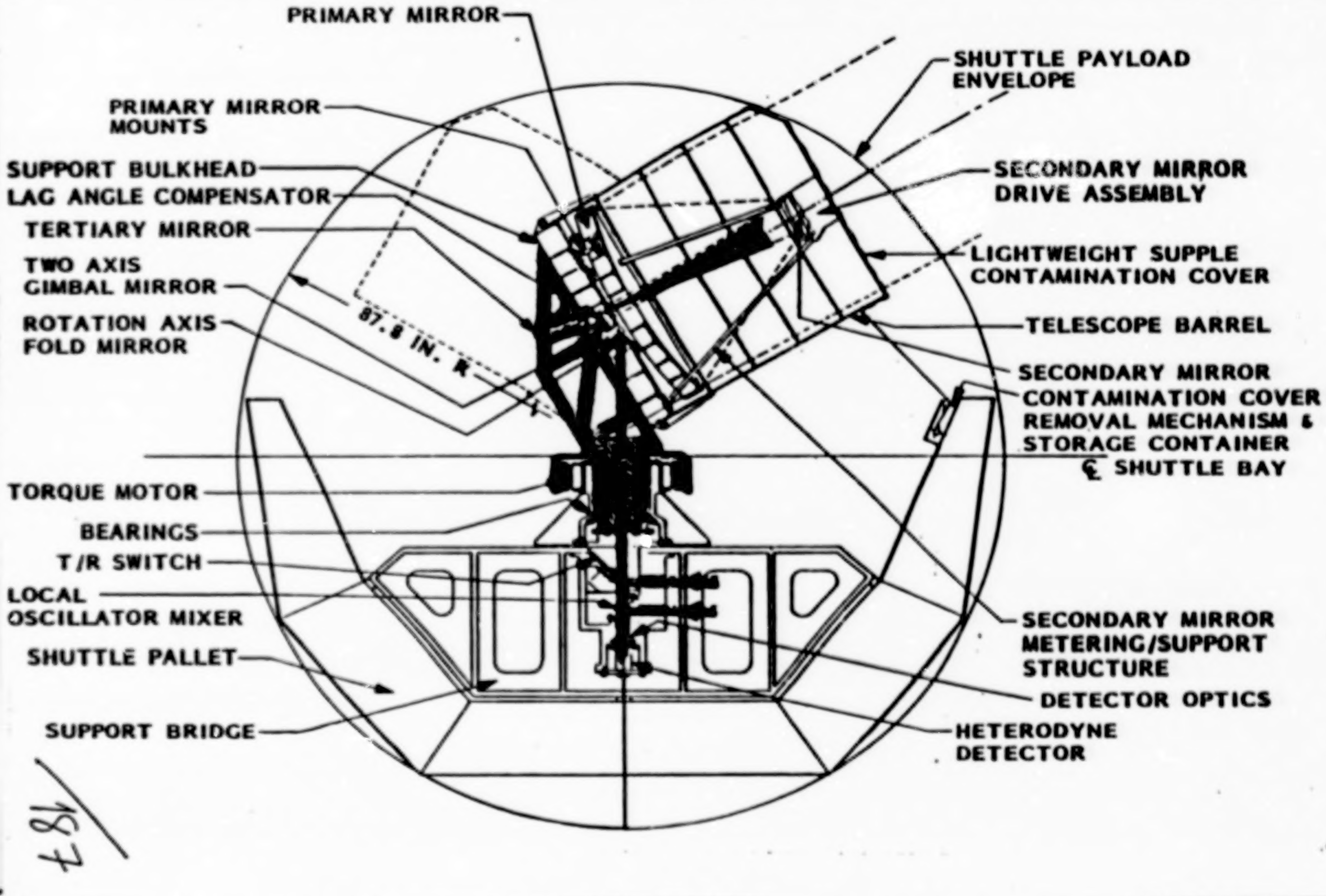
1.06 μm Nd:YAG COHERENT LIDAR SYSTEM

- SOLID-STATE
- COMPACT, MOPA CONFIGURATION
- ATMOSPHERIC WIND AND AEROSOL BACKSCATTER MEASUREMENTS
- MAXIMUM RANGE 20 KM
- VELOCITY RESOLUTION: < 1 METER/SEC
- RANGE RESOLUTION: <100 METERS
- OPERATIONAL IN FALL, 1987

- POTENTIAL BENEFITS OF USING EYESAFE SOLID-STATE LASERS
  - MORE COMPACT
  - IMPROVED LIFETIME
  - LOWER POWER CONSUMPTION
  - IMPROVED DETECTOR SENSITIVITY
  - IMPROVED VELOCITY RESOLUTION
  - IMPROVED RANGE RESOLUTION

- PROMISING EYESAFE SOLID-STATE LASERS ARE AVAILABLE
  - ACTIVATOR IONS Ho, Tm AND Er
  - CRYSTAL HOSTS YAG AND YLF

ROTATING TELESCOPE



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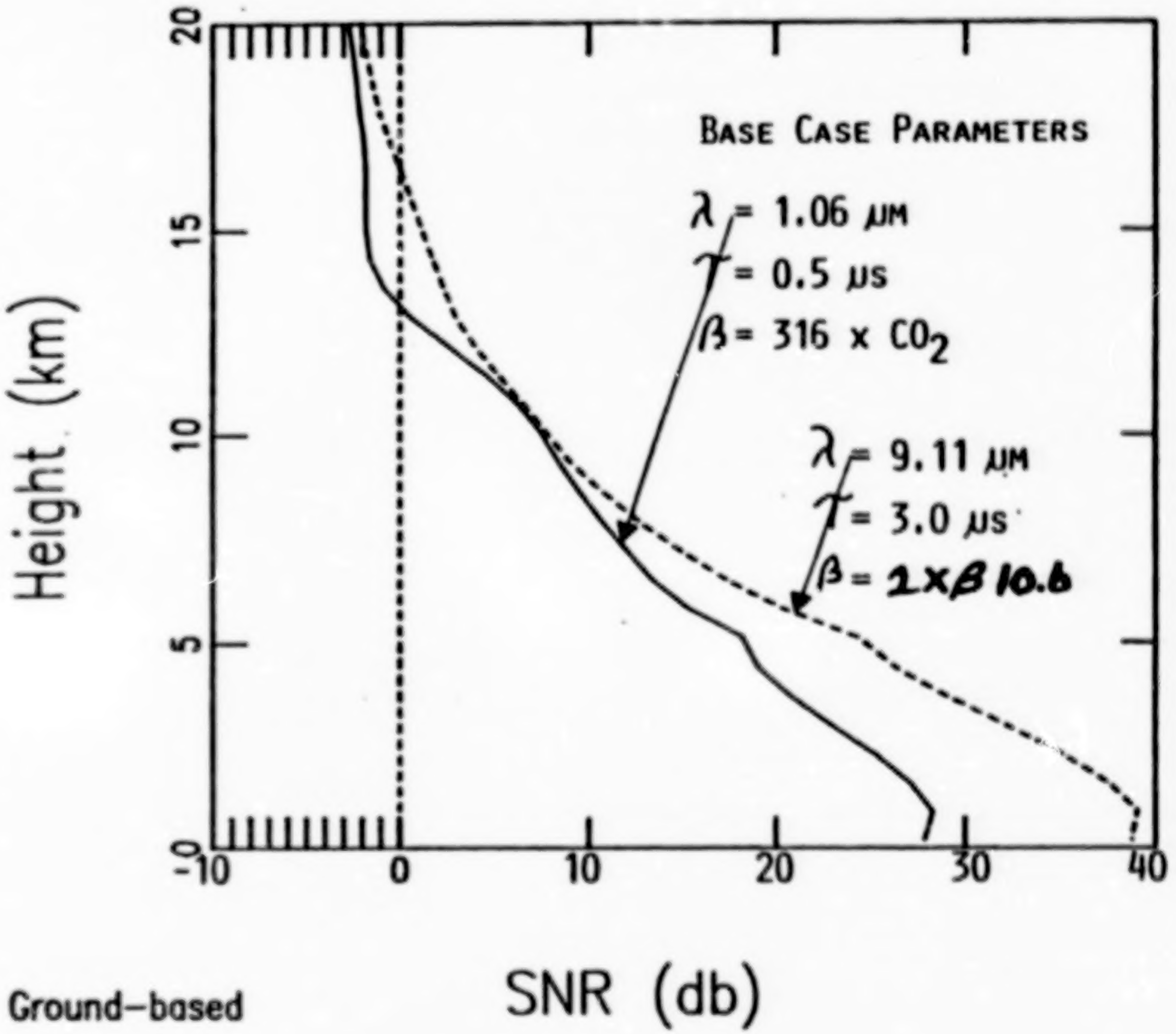
ASTRO

Windsat Free Flyer

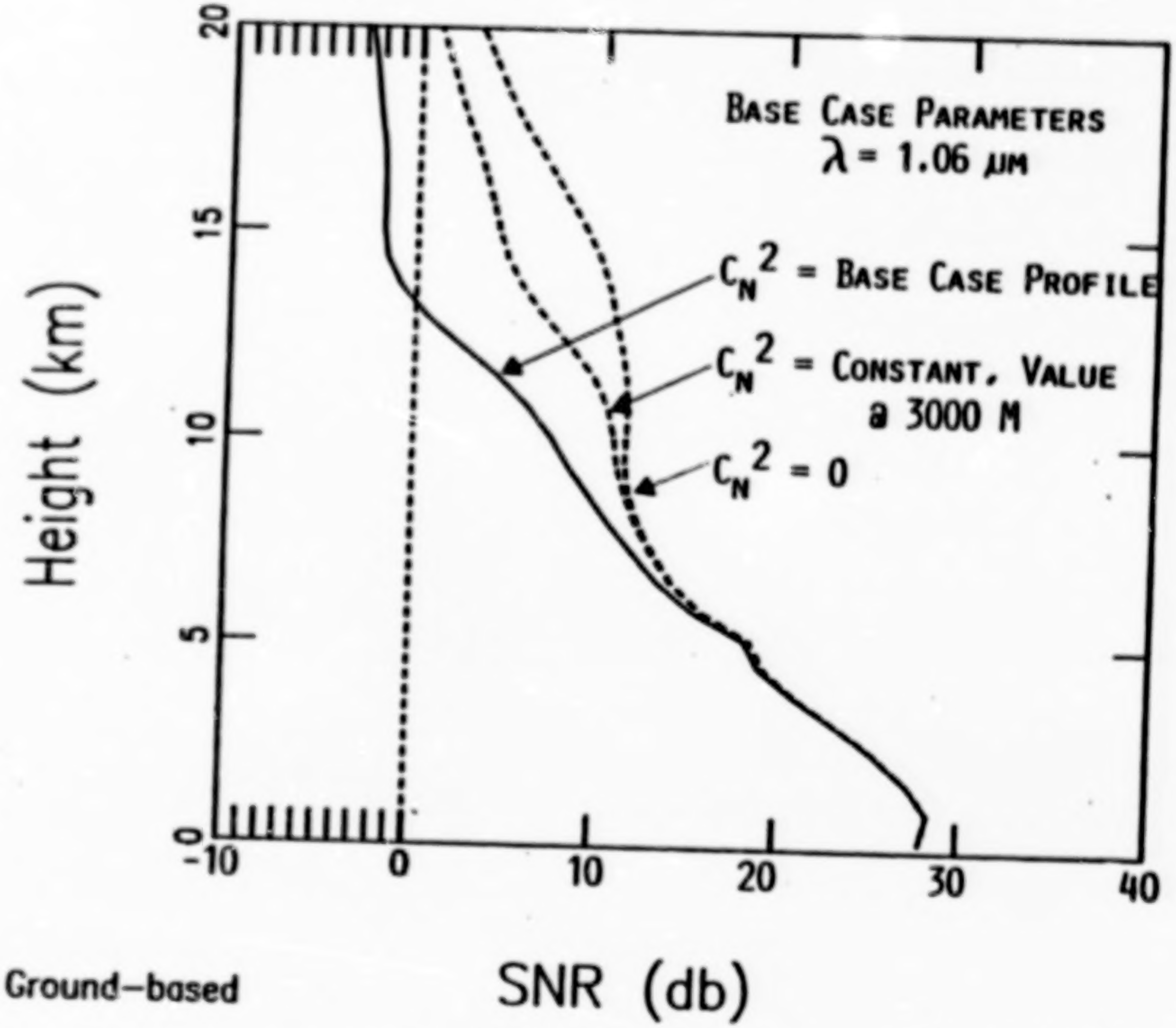
Astro Electronics

Signal to Noise Ratio



Ground-based

Signal to Noise Ratio



Ground-based

COMBINED RADAR-LASER RADAR WINDSHEAR CAPABILITY

1. OBTAIN SET OF MEASUREMENT REQUIREMENTS FROM THE FAA.

2. DETERMINE WINDSHEAR, MICROBURST DETECTION CAPABILITY OF COHERENT LASER RADAR.

   - USE DETAILED COMPUTER SIMULATION OF LASER WIND MEASURING PROCESS.

   - GENERATE AND INCORPORATE REALISTIC WINDS INTO SIMULATION.

   - DETERMINE MEASUREMENT ACCURACY, REQUIRED RANGE RESOLUTION, RANGE, LASER WAVELENGTH AND POWER, OPTICS SIZE, PULSE LENGTH, AND PULSE REPETITION FREQUENCY.

   - DETERMINE REQUIRED SCAN.

COMBINED RADAR-LASER RADAR WINDSHEAR CAPABILITY (CONT'D)

3. EVALUATE THE COHERENT LASER RADAR TECHNOLOGY TO MEET A SET OF MEASUREMENT REQUIREMENTS.

    -- CO_2 WAVELENGTHS

    -- EYESAFE WAVELENGTHS, SOLID-STATE

4. RECOMMEND A SET OF INSTRUMENT PARAMETER FOR BOTH A CO_2 AND A SOLID-STATE EYESAFE WAVELENGTH.

5. ANALYZE THE CAPABILITY OF A COMBINED RADAR -- LASER RADAR SYSTEM FOR ON-BOARD AIRLINER DETECTION OF WINDSHEAR.

6. SPECIFY A COMBINED RADAR -- LASER RADAR SYSTEM.

INFRA RED

P. Adamson
Turbulence Prediction Systems

AIRBORNE INFRARED REMOTE SENSING AIR TURBULENCE ADVANCE WARNING SYSTEM

PATRICK ADAMSON
ROBERT G. GRAY
DONALD R. ROGERS

TURBULENCE PREDICTION SYSTEMS

3005 30TH STREET, SUITE 200

BOULDER, COLORADO 80302

(303) 443-8157

PRODUCT

AIRBORNE INFRARED BASED
AIR TURBULENCE
ADVANCE WARNING SYSTEM

RESEARCH INSTRUMENT

- * 1,000 HOURS IN THE AIR
- * 98% PREDICTION RATE CAT
- * 100% PREDICTION RATE LLWS

OPERATIONAL SYSTEM

DEDICATED DUAL (LLWS/CAT)
INSTRUMENT

PREDICTIVE COMPONENT

- * NEW GENERATION SENSOR
- * MICROPROCESSOR BASED ALOGRITHM
- * CRT COCKPIT DISPLAY

REACTIVE COMPONENT

- * 3 AXIS ACCELEROMETER
- * ACCEPTS AIRCRAFT INPUTS

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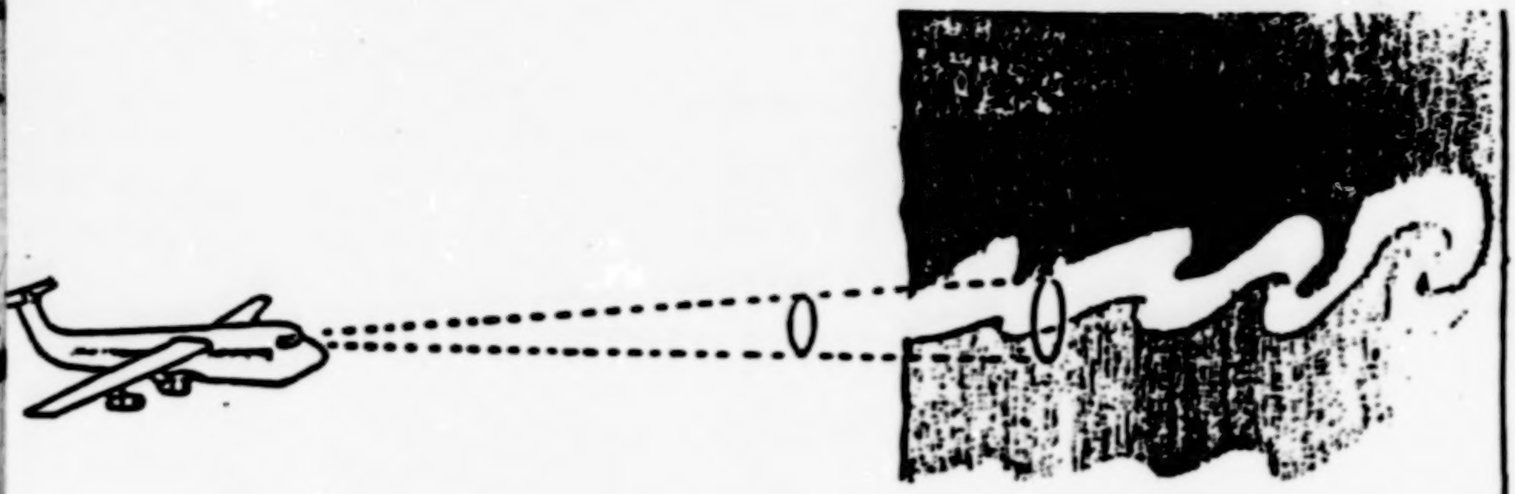

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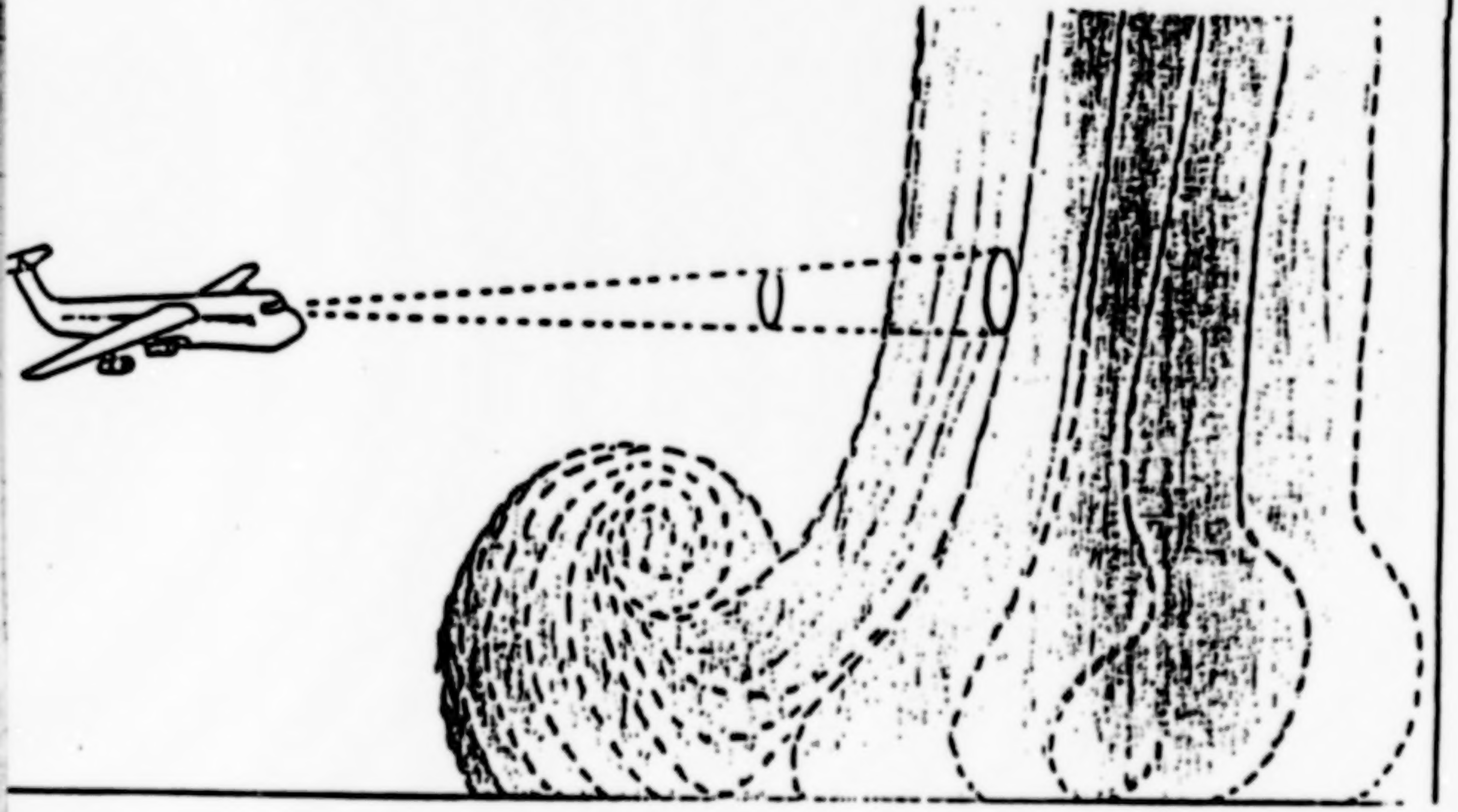

LLWS

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FAA'S INTEGRATED WIND SHEAR PROGRAM

The primary defense against wind shear is avoidance. This is why significant part of the Integrated FAA Wind Shear Program plan deals with the development of wind shear detection systems. Today's wind shear detection systems are relatively ineffective. ven when more sophisticated systems become available in the future, avoidance can never be 100% effective. For this reason, the flight crew must be trained to recognize a wind shear ncounter and take the appropriate recovery action. Both the National Research Council (NRC) and the National Transportation Safety Board (NTSB) recognized this need. The NTSB and NRC ecommended that the FAA work together with industry to develop n authoritative education and training program." (emphasis added)

1. TRAINING AIDS
2. TERMINAL INFORMATION
3. HAZARD CHARACTERIZATION
4. GROUND SENSORS
5. AIRBORNE SENSORS
    - A) "ESCAPE" – REACTIVE SYSTEMS
    - B) "AVOID" – PREDICTIVE SYSTEMS

EFERENCE: INTEGRATED FAA WIND SHEAR PROGRAM PLAN, 15 AUGUST 1986

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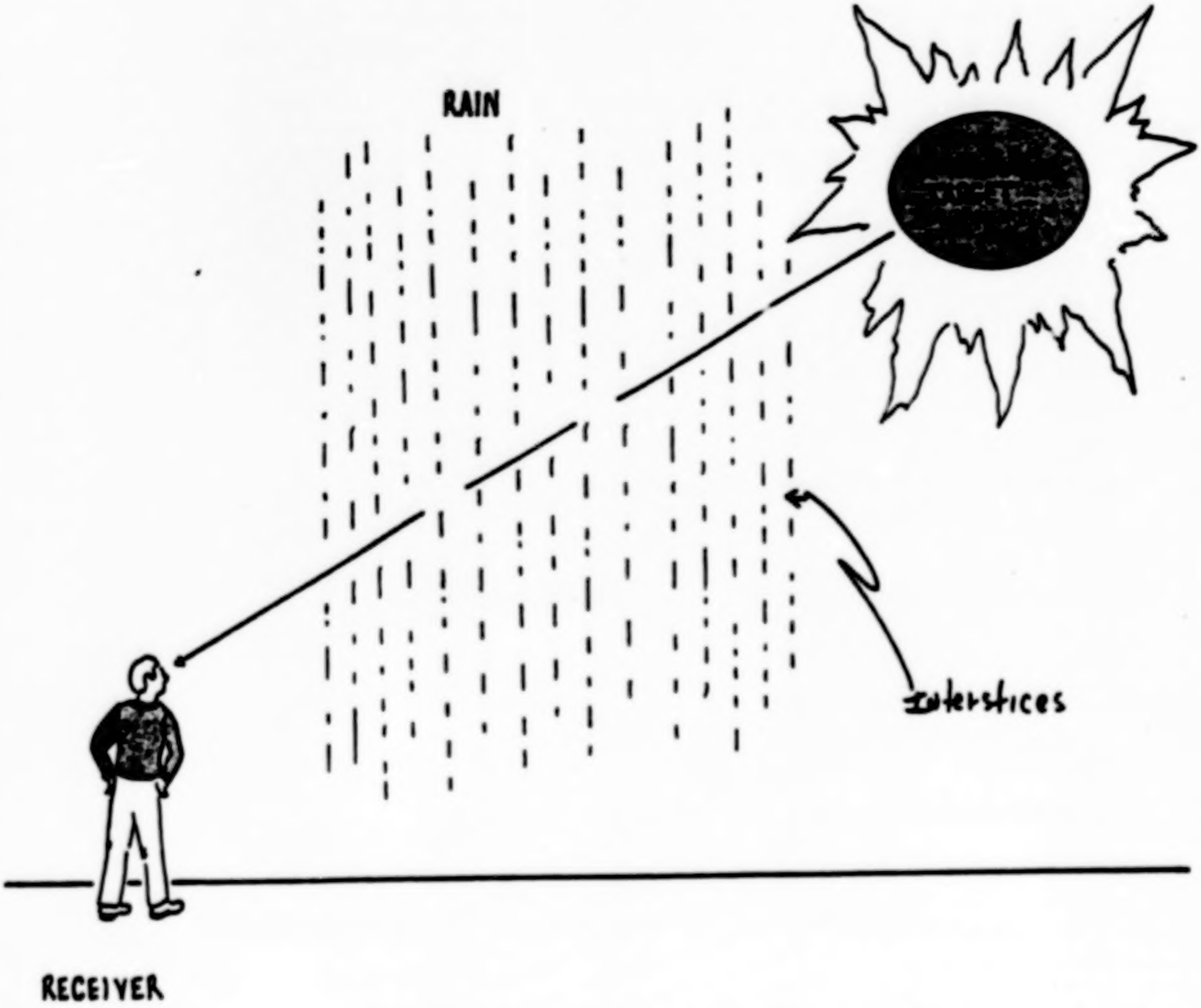
INFRARED SENSING TECHNIQUE



TBC-66

WHAT CAUSES WINDS?

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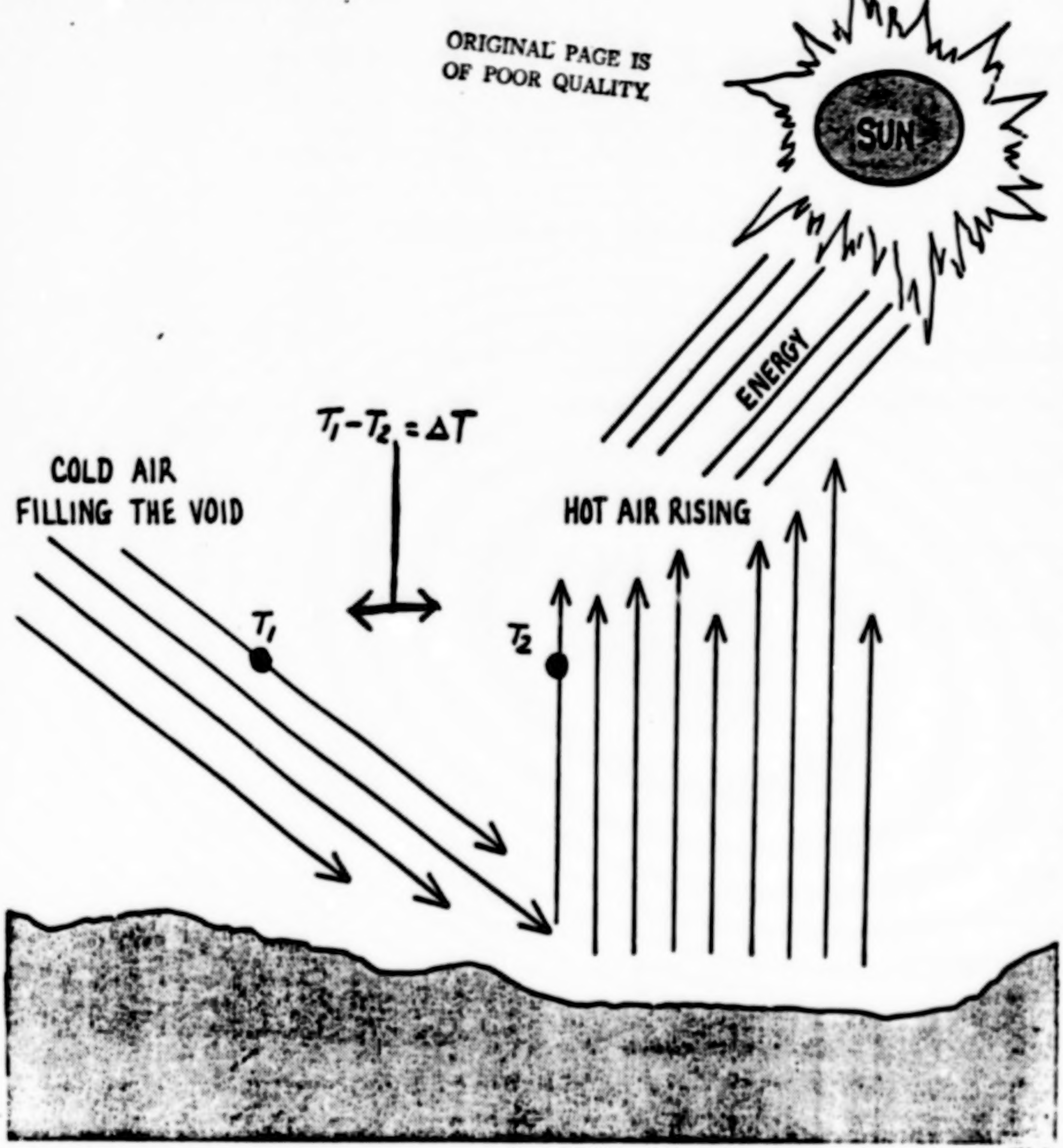

AIRBORNE "AVOID" PREDICTIVE SYSTEMS

PROBLEM: WIND SHEAR IMPLIES A CHANGE IN WIND SPEED/DIRECTION OF A MAGNITUDE WHICH IS DANGEROUS TO AIRCRAFT

CANDIDATE SENSORS

TECHNIQUE	MECHANISM	INFERRED INFO
INFRARED	dT/dt	WIND SPEED
RADAR	DOPPLER SHIFT	WIND SPEED
LASER	DOPPLER SHIFT	WIND SPEED
ACOUSTIC	DOPPLER SHIFT	WIND SPEED

	WEATHER	
TECHNIQUE	DRY	WET
INFRARED	VERY GOOD	GOOD
RADAR	POOR	GOOD
LASER	VERY GOOD	POOR
ACOUSTIC	UNPROVEN	UNPROVEN

IOW DO YOU PREDICT WINDS?

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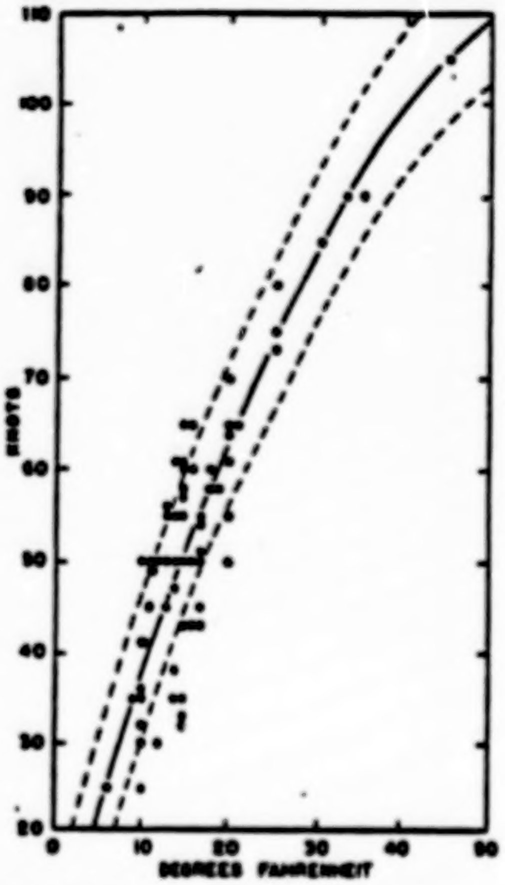
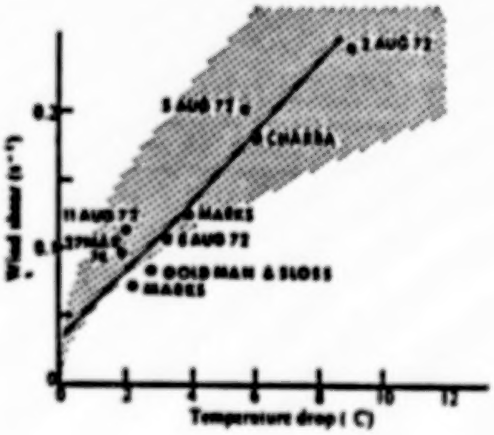


FIG. 1. Peak gusts and temperature differences in thunderstorms with regression curve and standard error of estimate. Abscissa is temperature just prior to the thunderstorm minus temperature immediately after the downrush. See text for further explanation.

Fig. 4 Measured wind shear plotted against temperature drop from the ambient atmosphere to the density current. The experimental data points, as described in the text, nearly fit a straight line, while the overlay stippled area represents approximate bounds on the shear predicted by equation (7).



REFERENCE: "A BASIS FOR FORECASTING PEAK WIND GUSTS IN NON-FRONTAL HUNDERSTORMS"; BY E.J. FAWBUSH AND .C. MILLER; BULLETIN AMERICAN METEOROLOGICAL SOCIETY; VOL. 35, O. 1, JANUARY, 1954.

REFERENCE: "WIND SHEAR OBSERVATIONS IN THUNDERSTORM DENSITY CURRENTS"; BY F.F. HALL AND W.D. NEFF; NATURE, VOL 264, DECEMBER 2, 1976.

HOW CAN INFRARED INFER WINDS?

MEASURE TEMPERATURE

IN TWO SPATIAL LOCATIONS

CHANGE IN TEMP OVER TIME -

INFERRED WINDS

HISTORICAL LLWS RESEARCH RESULTS

NASA LEARJET – 1978 CALIFORNIA
JAWS PROJECT – 1982 DENVER, CO

TEST PROTOCOL: A HIT IF THE ALARM SOUNDS AND A SHEAR OF GREATER THAN 0.1 SEC^{-1} WAS ENCOUNTERED, OTHERWISE A MISS
REFERENCE: SNYDER

PREDICTION RESULTS: 100.0% HITS

MISSED ENCOUNTERS: 0.0%

WARNING RESULTS:

MINIMUM WARNING	14 SECONDS
MAXIMUM WARNING	68 SECONDS
AVERAGE WARNING	46 SECONDS

LLWS CONCLUSIONS

"THE EFFECTS OF "LOOKING" THROUGH LIGHT RAIN AND VIRGA DO NOT APPEAR TO POSE A PROBLEM AND ARE BEING STUDIED FURTHER."

REFERENCE: "APPLICATION OF INFRARED RADIOMETERS FOR AIRBORNE DETECTION OF CLEAR AIR TURBULENCE AND LOW LEVEL WIND SHEAR"; BY P.M. KUHN; FINAL REPORT DECEMBER 31, 1982 - MARCH 31, 1985.

"ANALOG STUDY OF THE LONGITUDINAL RESPONSE OF A SWEPT-WIND TRANSPORT AIRPLANE TO WIND SHEAR AND SUSTAINED GUSTS DURING LANDING APPROACH"; BY C.T. SNYDER, NASA AMES RESEARCH CENTER; NASA TN D4477; 1968.

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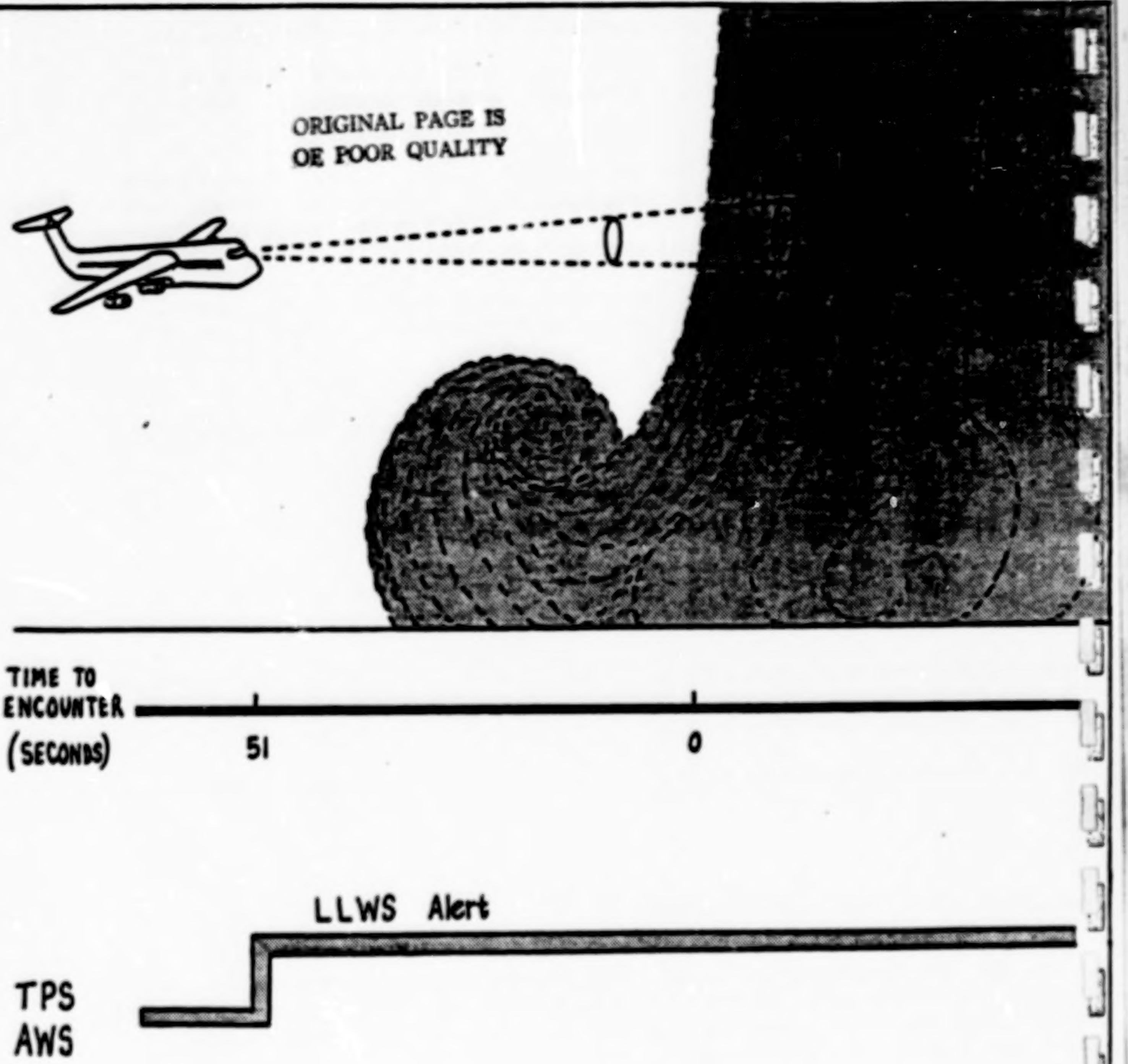

TPS's INFRARED LLWS ADVANCE WARNING DIAGRAM

TBC-8

HISTORICAL LLWS RAIN RESEARCH

JAWS PROJECT – 1982 DENVER, CO
CESSNA 207 – 1985 HUNTSVILLE, AL

TEST GOALS: EVALUATE IR ADVANCE WARNING SYSTEM IN LIGHT/MODERATE RAIN

- ASSESS PREDICTION
- ASSESS FALSE ALARMS

TEST PROTOCOL: A HIT IF THE ALARM SOUNDS AND A SHEAR OF GREATER THAN .1 SEC^{-1} WAS ENCOUNTERED, OTHERWISE A MISS

A SUCCESSFUL PREDICTION REQUIRED AN ADVANCE WARNING OF GREATER THAN 40 SECONDS

RESEARCH RESULTS:

19 RAIN TRACTS FLOWN

8 TRACTS SHEAR CONFIRMED

11 TRACTS NO SHEAR ENCOUNTERED

PREDICTION RESULTS: 6 OUT OF 8

MISSED ENCOUNTERS: 2 (5, 17 SEC)

FALSE ALARMS: 4 ALARMS SOUNDED BUT NO SHEAR CONFIRMED IN 11 NO SHEAR TRACTS

REFERENCE: "AIRBORNE INFRARED WIND SHEAR DETECTOR PERFORMANCE IN RAIN OBSCURATION"; BY P.M. KUHN AND P.C. SINCLAIR, ARIS, INC.; PAPER PRESENTED AT AIAA MEETING JANUARY 18, 1987; RENO, NEVADA.

HISTORICAL CAT RESEARCH RESULTS

NASA CV 990 – 1979

TEST PROTOCOL: A HIT IF THE ALARM SOUNDS AND A SHEAR OF GREATER THAN 0.2 G ACCELERATION WAS ENCOUNTERED, OTHERWISE A MISS

PREDICTION RESULTS: 98.32% HITS

MISSED ENCOUNTERS: 1.68%

ANALYSIS OF MISSED ENCOUNTERS:

112 LIGHT CAT	1 MISSED
4 MODERATE CAT	1 MISSED
3 SEVERE CAT	0 MISSED

"FALSE" ALARMS: 8.51%

REFERENCE: "FINAL STATISTICAL REPORT ON AVIATION SAFETY TECHNOLOGY (IN-FLIGHT DETECTION AND PREDICTION OF CLEAR AIR TURBULENCE)"; BY LOIS STEARNS AND VALERIE NOGAY, NOAA; FOR NASA AMES RESEARCH CENTER; DECEMBER 1, 1979.

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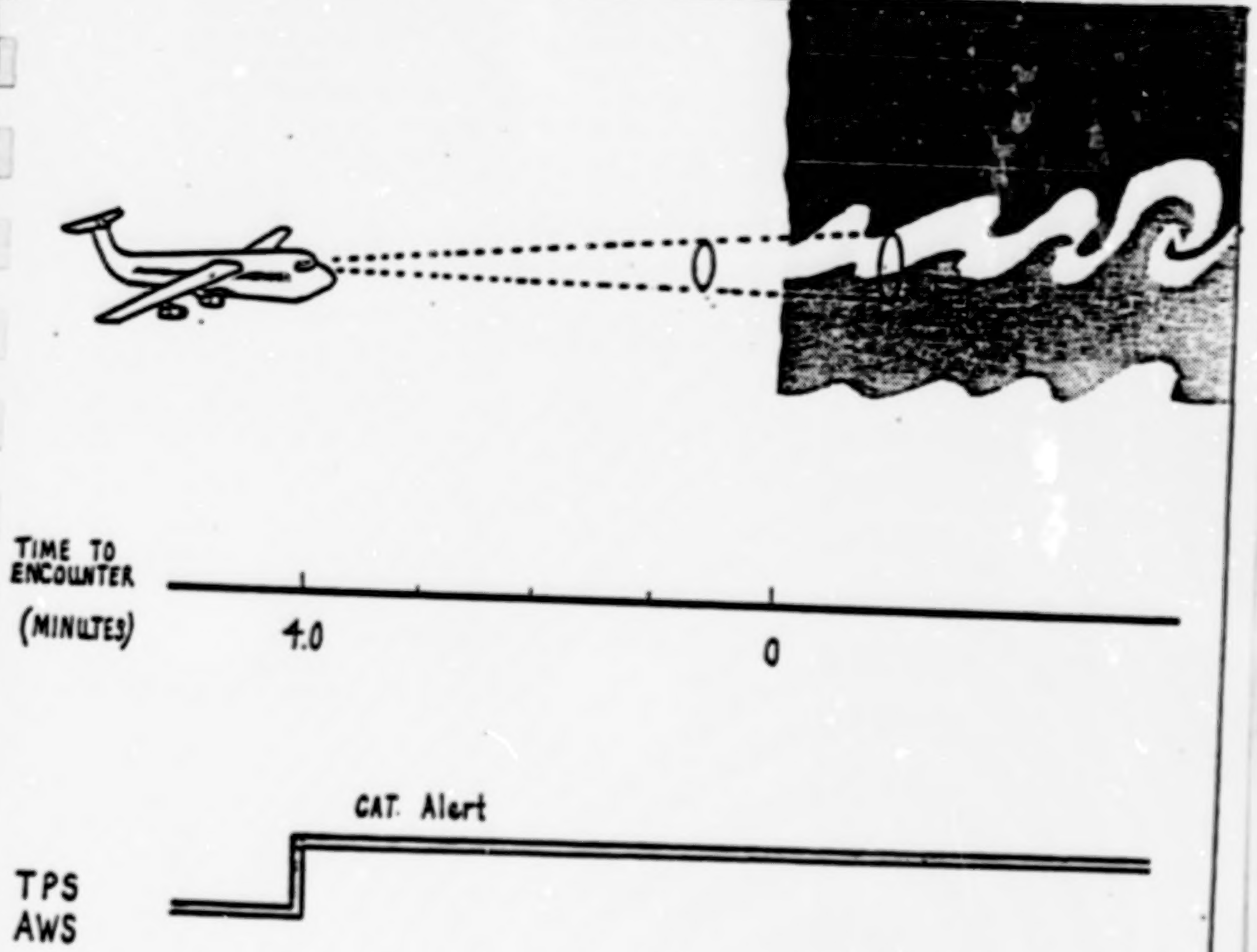


TPS's Infrared CAT Advance Warning Diagram

TBC-96

DIFFICULTIES ENCOUNTERED IN PREDICTING DYNAMIC EVENTS

EVEN IF THE FORECAST OR WARNING TECHNIQUES ARE PERFECTLY ACCURATE, THE MOST ONE CAN EXPECT IS AN 80% VERIFICATION RATE DUE TO THE MANY FACTORS INVOLVED AND THE RANDOM NATURE OF DYNAMIC WEATHER.

REFERENCE: "ASPECTS OF CLEAR AIR TURBULENCE SEVERITY FORECASTING AND DETECTION"; BY L.J. EHERNBERGER, DRYDEN FLIGHT RESEARCH FACILITY, NASA AMES RESEARCH CENTER; PRESENTED AT INTERNATIONAL CONFERENCE ON THE AVIATION WEATHER SYSTEM, MONTREAL, MAY 4-7,1981.

"EVEN WHEN MORE SOPHISTICATED SYSTEMS BECOME AVAILABLE IN THE FUTURE, AVOIDANCE CAN NEVER BE 100% EFFECTIVE."

REFERENCE: INTEGRATED FAA WIND SHEAR PROGRAM PLAN, 15 AUGUST 1986

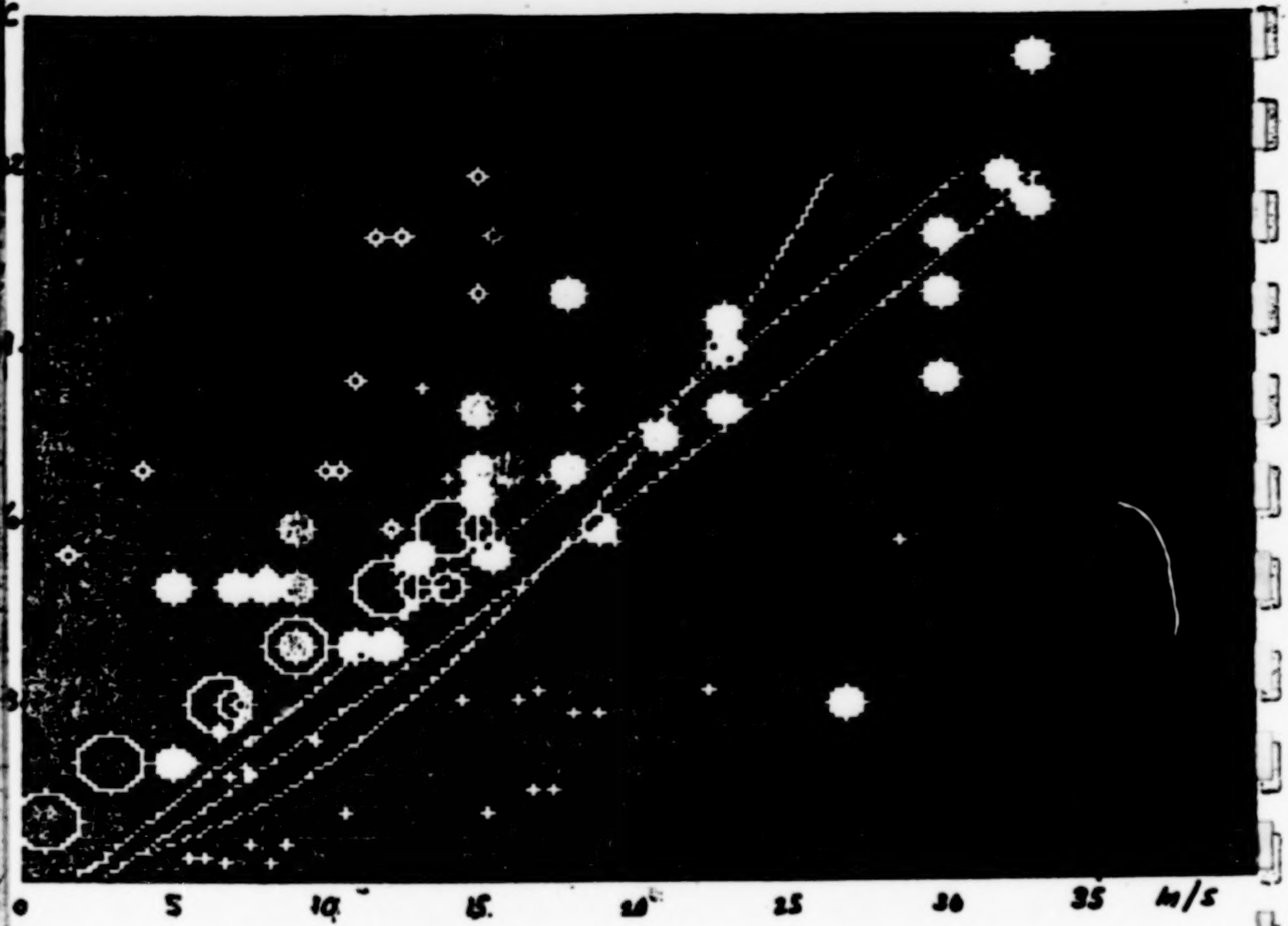
NEW UNDERSTANDING TO FURTHER ASSESS INFRARED SENSING OF AIR TURBULENCE

* HIGH CORRELATION OF WIND AND TEMPERATURE BY 7 TECHNIQUES

1. SURFACE – MEASURE WIND, MEASURE TEMP
2. ACOUSTIC – MEASURE WIND, CORRELATE TEMP
3. DOPPLER RADAR – MEASURE WIND, CORRELATE TEMP
4. INFRARED – MEASURE TEMP, CORRELATE WINDS
5. BOUYANCY EQ – INPUT CHANGE TEMP, INFER VERTICAL WINDS
6. PAM STATIONS – MEASURE WIND, MEASURE TEMP
7. DELTA 191 – MEASURE WIND AND MEASURE TEMP

* DELTA 191 ACCIDENT

1. NTSB DRAFT PAPER – CARACENA
2. WIND/TEMPERATURE CORRELATION



Plot of winds (m/s) against temperature (°C)

Turbulence Prediction Systems P.A. 2/23/87

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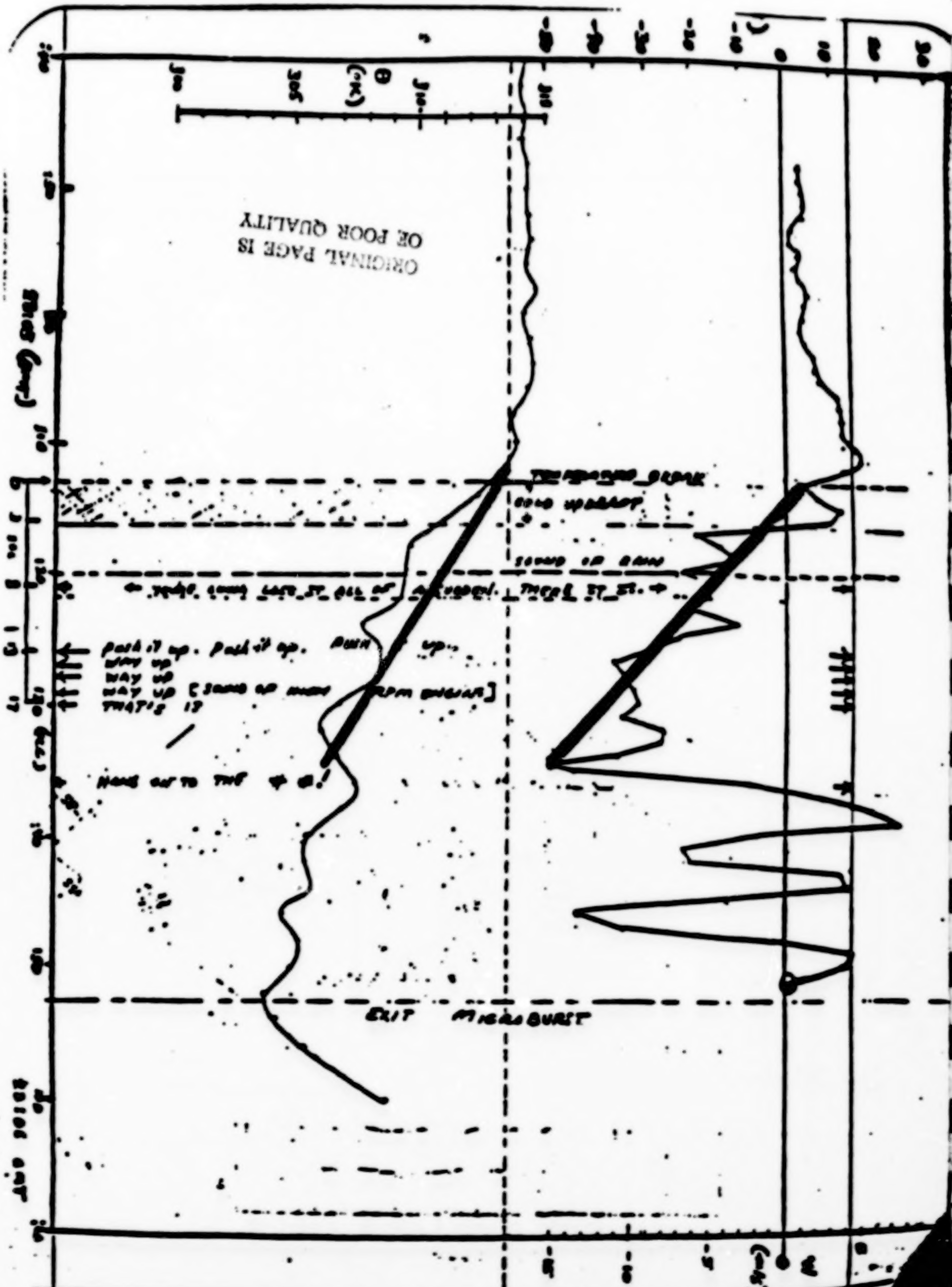

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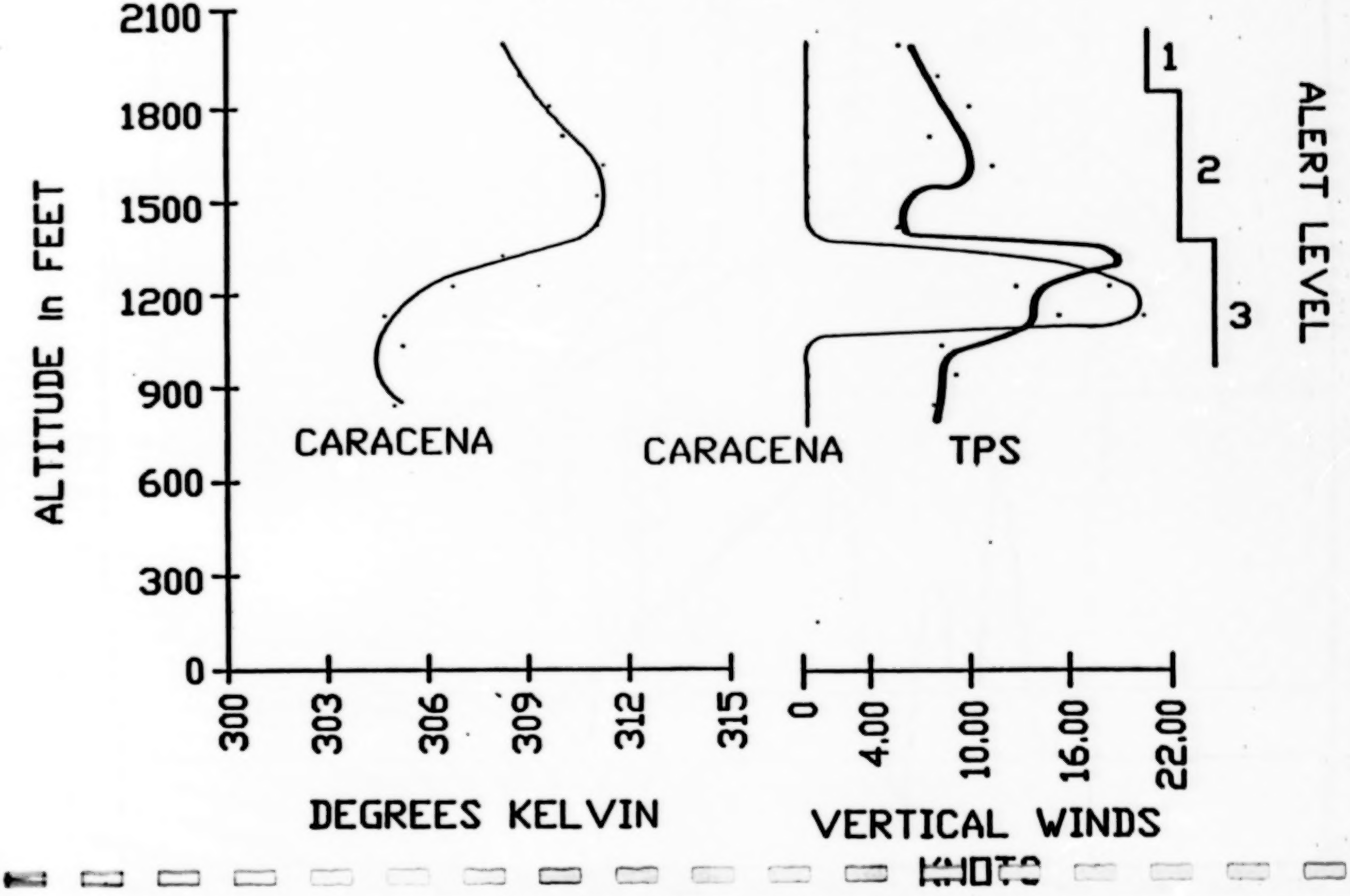
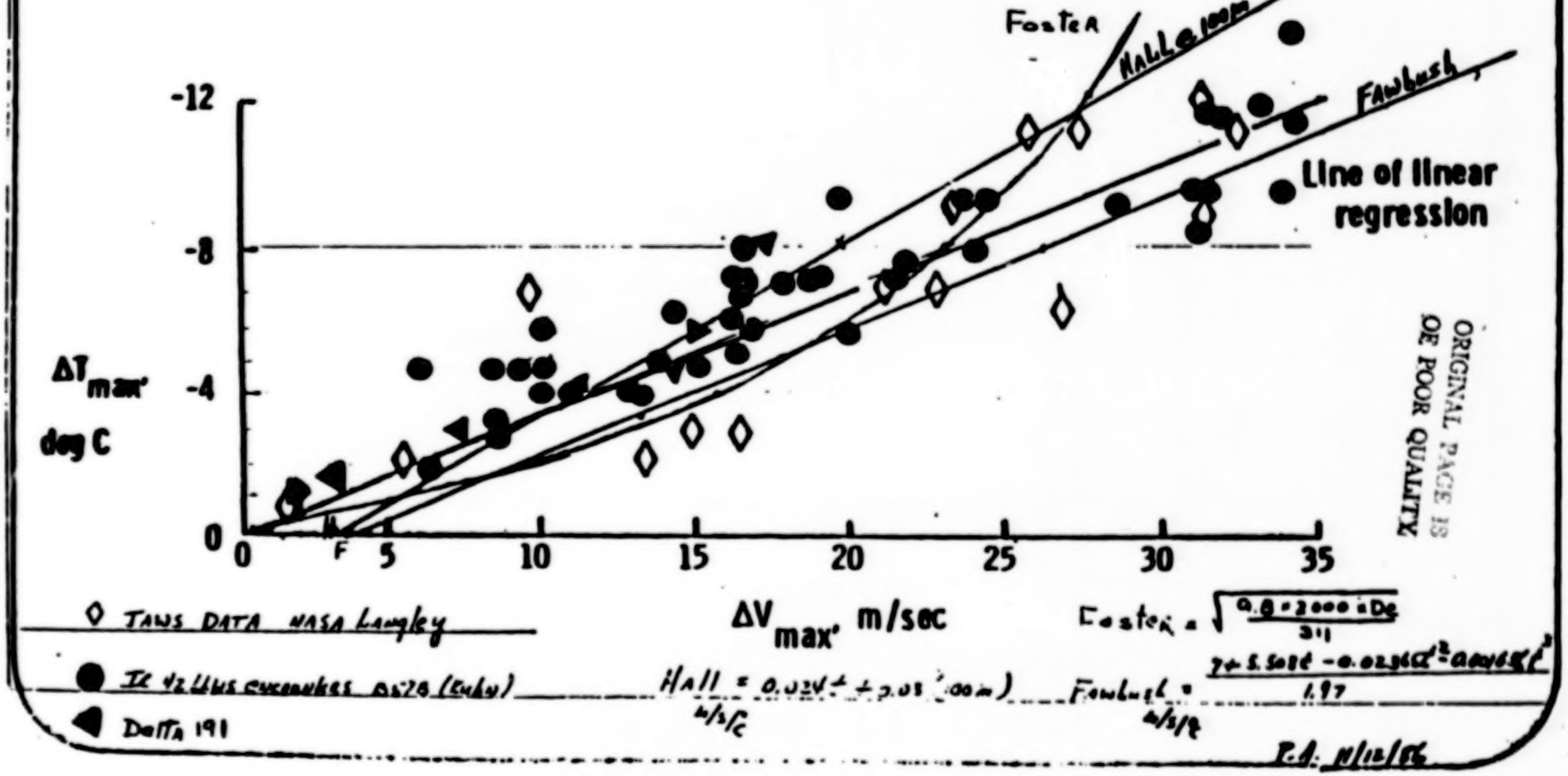
DELTA FLIGHT 191
TPS WINDS



RELATION BETWEEN PEAK WIND SHEAR OUTFLOW AND MAXIMUM TEMPERATURE CHANGE RELATIVE TO AMBIENT FOR SIMULATED MICROBURST ENVIRONMENT



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OUR CONCLUSIONS: WIND VS TEMP

* ACTUAL ENCOUNTER HIGH CORRELATION WITH 6 RESEARCHERS REGARDING WINDS DRIVEN BY TEMPERATURE

* WINDS CAN BE INFERRED BY TWO INFRARED SPATIAL VOLUME TEMPERATURE MEASUREMENTS

* INFERRED WINDS CAN BE USED WITH CONFIDENCE TO ISSUE LLWS COCKPIT ALERT

IF AIRBORNE INFRARED WAS AVAILABLE ON DELTA 191 THE CREW WOULD HAVE HAD A 60 SECOND ADVANCE WARNING.

WHAT IS REQUIRED FOR AN IMPROVED AIRBORNE AIR TURBULENCE PREDICTION SYSTEM?

- * IMPROVE ABILITY TO SENSE TEMPERATURE IN FRONT OF THE AIRCRAFT

- * EXPAND ATMOSPHERIC MODEL TO INFER HORIZONAL AND VERTICAL WINDS

- * IMPROVE THE ALGORITHMS WHICH TRANSLATES INFERRED WINDS INTO COCKPIT ALERTS

IMPROVED TEMPERATURE SENSOR

OLD STANDARD INFRARED RADIOMETER
+/- .5°C

NEW GENERATION INFRARED RADIOMETER
+/- .05°C

AN EXPANDED ATMOSPHERIC MODEL

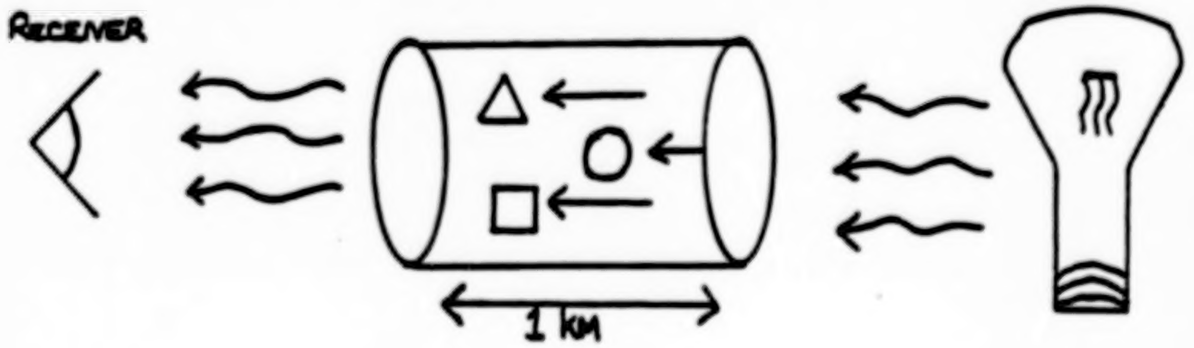
- RAIN
- HORIZONAL AND VERTICAL WINDS

STATE OF THE ART ALOGRITHMS

- MICROPROCESSOR BASED
  - COMPUTE HAZARD INDEX
  - DISPLAY ON CRT

TURBULENCE PREDICTION SYSTEMS

RAIN AND ITS IMPACT ON INFRARED TRANSMISSION



ELEMENTS THAT EFFECT TRANSMISSION

△ - UNIFORM DISTRIBUTED GASES

□ - WATER VAPOR

○ - LIQUID WATER (RAIN)

INFRARED TRANSMISSION MODEL OF THE ATMOSPHERE

PURPOSE: COMPUTE ADVANCE WARNING TIME IN WEATHER

STEPS: 1-COMPUTE TRANSMISSION THROUGH UNIFORM DISTRIBUTED GASES

2-COMPUTE TRANSMISSION THROUGH WATER VAPOR

3-COMPUTE TRANSMISSION THROUGH LIQUID WATER (RAIN)

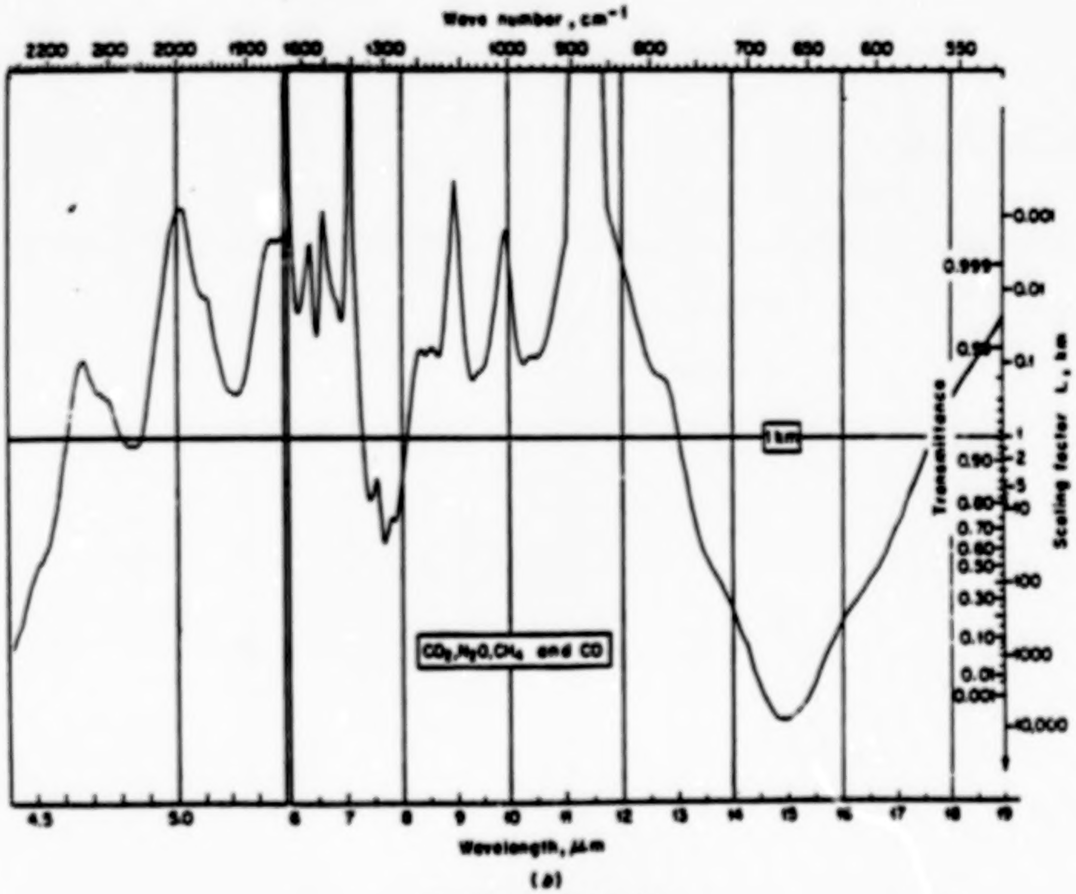
4-COMPUTE TOTAL TRANSMISSION

5-FROM TOTAL TRANSMISSION COMPUTE LOOK DISTANCE

6-FROM LOOK DISTANCE COMPUTE ADVANCE WARNING (IN SECONDS)

UNIFORM DISTRIBUTED GASES

INFRARED IS ABSORBED BY THE UNIFORM DISTRIBUTED GASES AS A FUNCTION OF WAVE LENGTH



(a)

Fig. 17 *(Continued)*

NOTE: TRANSMITTANCE/KILOMETER

FOR EXAMPLE:

@ 13.5 MICRONS

TRANSMITTANCE = .60/KM

@ 5 KM

TRANSMITTANCE = (.60)^5 = 7.8%

WATER VAPOR

INFRARED IS ABSORBED BY WATER VAPOR AS A FUNCTION OF WAVE LENGTH

AS WITH THE UNIFORM DISTRIBUTED GASES, WATER VAPOR REDUCES TRANSMISSION

FOR EXAMPLE:

CASE	TEMP	REL HUM	TRANSMISSION
1	30°C	30%	100%
2	30°C	60%	80%
3	30°C	100%	67%

REFERENCE: HANDBOOK OF OPTICS; WALTER G. DRISCOLL, EDITOR; McGRAW-HILL BOOK COMPANY; 1978; FIGURE 16, PAGE 14-41.

LIQUID WATER (RAIN)

INFRARED IS ABSORBED BY RAIN AS A FUNCTION OF RAIN DROP SURFACE AREA

REFERENCE: THE INFRARED HANDBOOK; WILLIAM L. WOLKE AND GEORGE J. ZISSIS, EDITOR; THE INFRARED INFORMATION AND ANALYSIS CENTER; 1978.

THUS AS WITH UNIFORM DISTRIBUTED GASES AND WATER VAPOR RAIN REDUCES TRANSMISSION

RAIN DROP SURFACE AREA

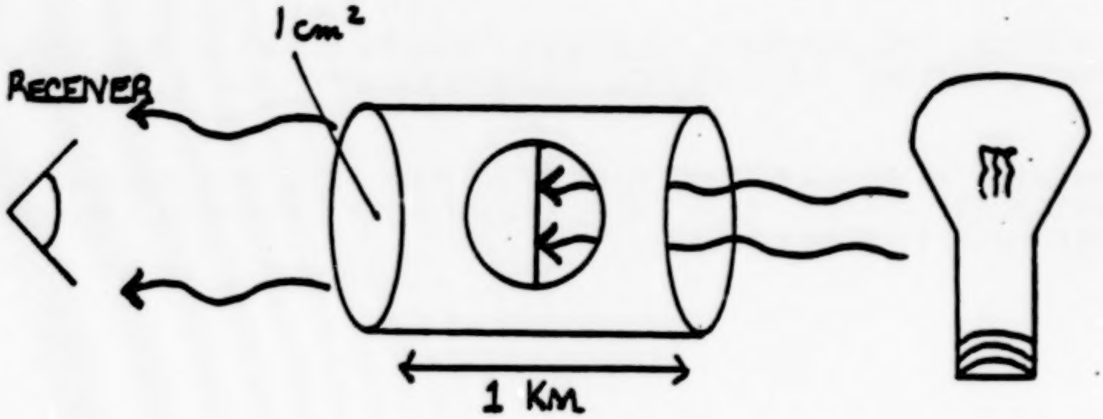
	DROP #1	DROP #2
DROP DIAMETER	2.0 mm	.6 mm
DROP VOLUME	41.2 mg	8.4 mg
DROP SURF AREA	12.6 mm^2	4.3 mm^2
# OF DROPS	1	5
TOT DROP VOL	41.2 mg	41.2 mg
TOT SURF AREA	12.6 mm^2	21.5 mm^2

NOTE: WITH A CONSTANT VOLUME

AS DROP SIZE DECREASES

SURFACE AREA INCREASES

LIQUID WATER (RAIN)



ONE-HALF OF ALL RAIN DROP SURFACE AREA ABSORBS ALL INFRARED ENERGY IMPINGING O IT

POWER = WATT SECONDS

COMPUTE SURFACE AREA PASSING THROUGH SAMPLE VOLUME PER SECOND

TRANSMISSION = $1\text{cm}^2 - \sum$SURFACE AREA

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HLWS PREDICTION TIME AS A FUNCTION OF HUMIDITY, RAIN, DROP SIZE

HUMIDITY

3 - 3 grams/cm^2/km

2 - 2 grams/cm^2/km

1 - 1 grams/cm^2/km

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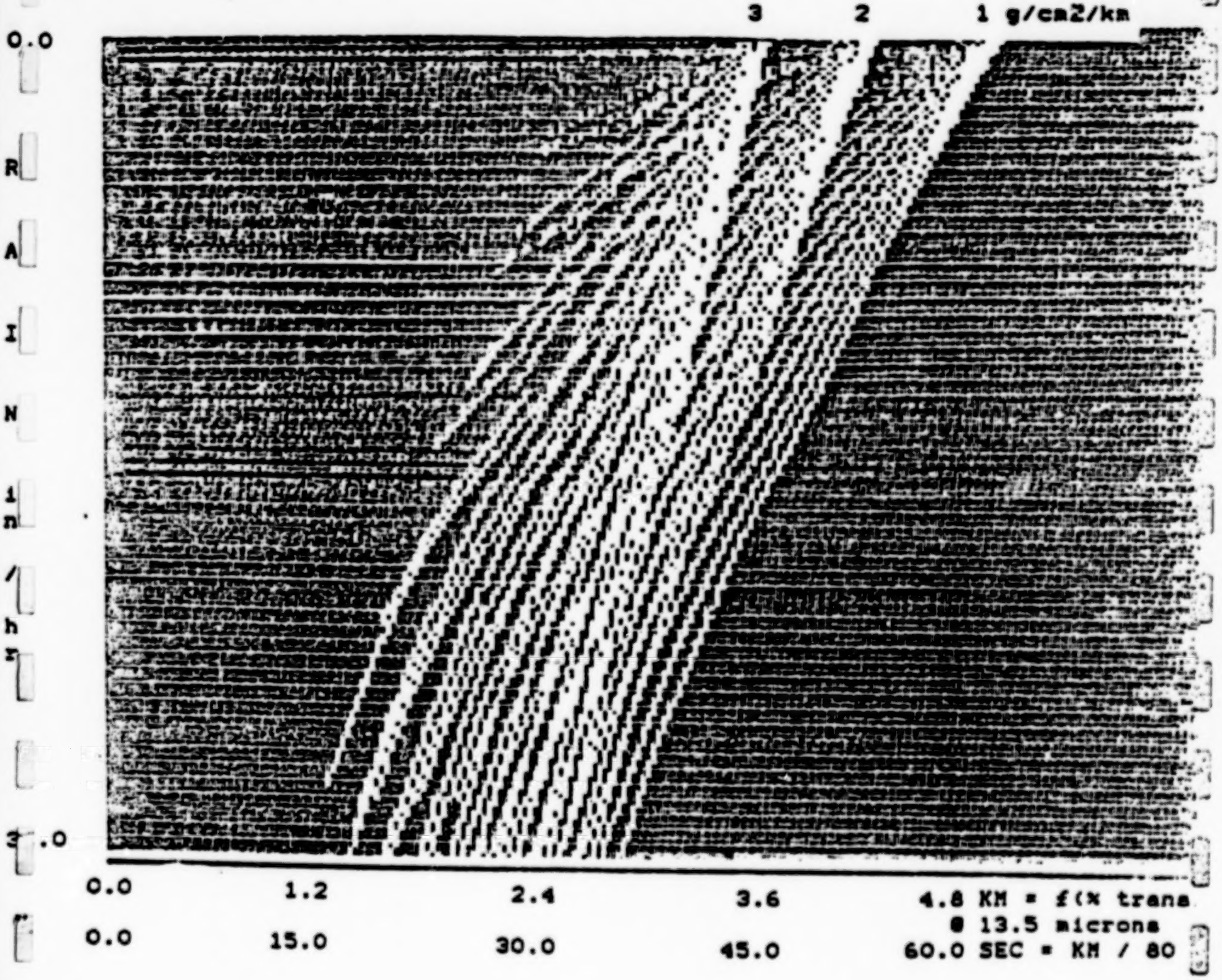
RAIN

0.0 - 38.0 inches/hour

DROP SIZE

0.01 - 0.30 cm



TOTAL TRANSMISSION

TOTAL TRANSMISSION =

TRANSMISSION (UNIFORM DIST GASES)

*

TRANSMISSION (WATER VAPOR)

*

TRANSMISSION (LIQUID WATER)

WHEN TOTAL TRANSMISSION = A SET CONSTANT, LOOK DISTANCE IS DEFINED

WITH LOOK DISTANCE AT 4.8 KM AND

LANDING SPEED AT 80 M/S

ADVANCE WARNING = 60 SECONDS

RAIN DROP DISTRIBUTION WITH INTENSITY

THE HEAVIER THE RAIN RATE
THE LARGER THE AVERAGE DROP SIZE

FOR EXAMPLE:

.05 INCH / HOUR RAIN RATE

MEDIAN DROP SIZE = 1 mm

4.00 INCH / HOUR RAIN RATE

MEDIAN DROP SIZE = 3 mm

REFERENCE: "THE RELATION OF RAINDROP-SIZE TO INTENSITY"; BY J. OTIS LAWS AND DONALD A PARSONS; TRANSACTIONS, AMERICAN GEOPHYSICAL UNION 24, PART II, 1943.

"THE DISTRIBUTION OF RAINDROPS WITH SIZE"; BY J.S. MARSHALL AND W. McK. PALMER; JOURNAL OF METEOROLOGY, VOLUME 5, AUGUST 1948.

LLWS PREDICTION TIME AS A FUNCTION OF RAIN, DROP SIZE

RAIN

0.0-38.0 inches/hour

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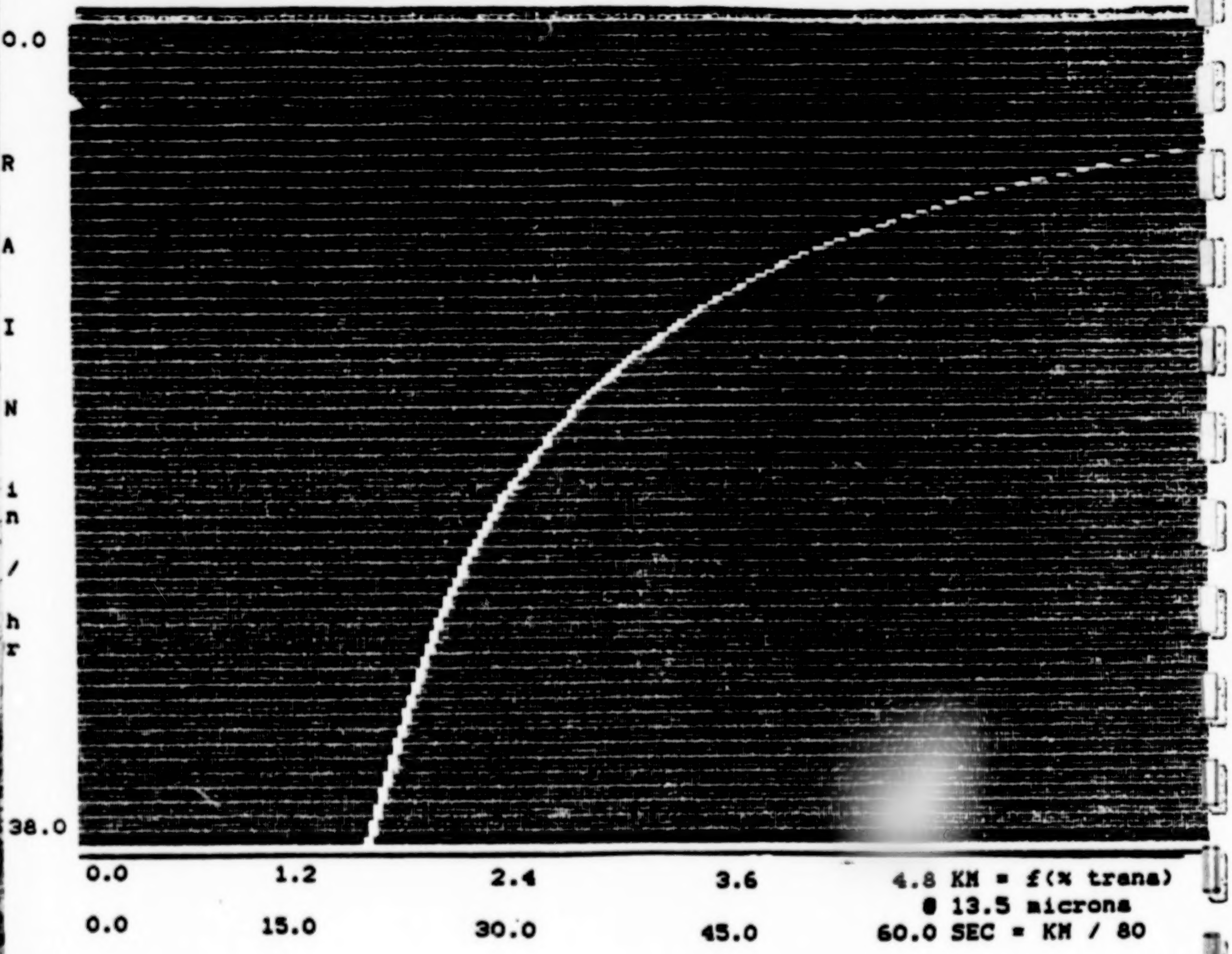
DROP SIZE

determined by Marshall equation
drop size range from 0.05-0.8 cm.



OBSERVED RAIN RATE WITH MICROBURSTS

FLOWS DATA

1984

MEMPHIS, TENNESSEE

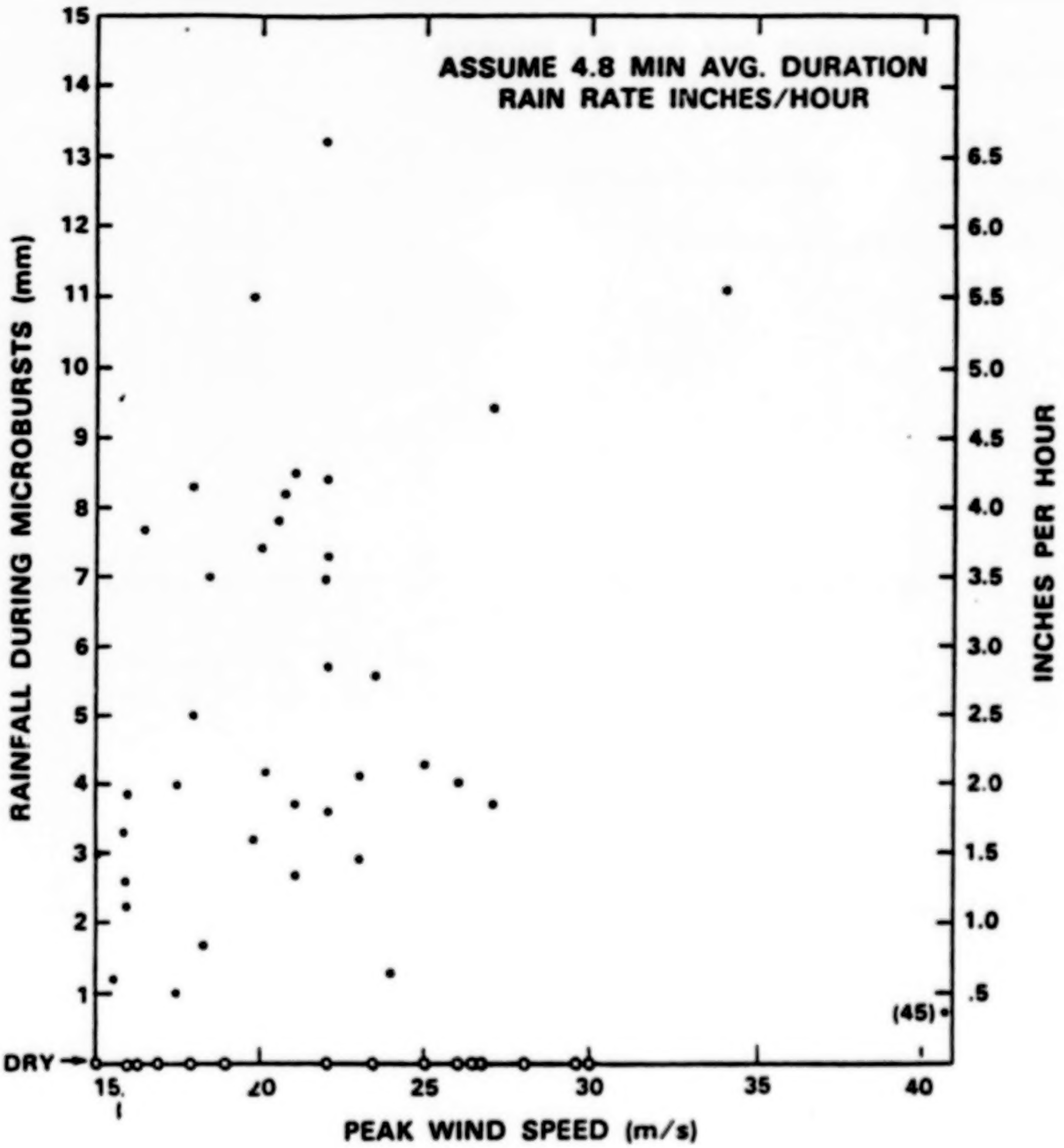
MIT LINCOLN LABS

RESULTS:

AVE DURATION RATE	4.8 MINUTES
AVE RAIN RATE	3.0 IN/HR
MAX RAIN RATE	6.5 IN/HR

REFERENCE: "LOW-ALTITUDE WIND SHEAR CHARACTERISTICS IN THE MEMPHIS, TENNESSEE AREA BASED ON MESONET AND LLWS DATA"; BY M.M. WOLFSON, J.T. DISTEFONO AND T.T. FUJITA; 14TH CONFERENCE OF SEVERE LOCAL STORMS, AMERICAN METEOROLOGY SOCIETY; 1985.

RAINFALL RATE vs PEAK WIND



ASSUME 4.8 MIN AVG. DURATION
RAIN RATE INCHES/HOUR

AIRBORNE INFRARED RESEARCH IN RAIN

JAWS PROJECT – 1982 DENVER, CO
CESSNA 207 – 1985 HUNTSVILLE, AL

VERFICATION OF MICROBURSTS

MIN ADVANCE WARNING	$\geq$40.00 SEC
DU/DZ	$\geq$ .15 SEC^{-1}
AIR SPEED CHANGE	$\geq$30.00 KNOTS
VECTOR DIFFERENCE	$\geq$30.00 KNOTS

RESULTS:

19 RAIN TRACTS FLOWN

- 8 WITH SHEAR
    - 6 HITS OUT OF 8
    - 2 MISSES (5 AND 17 SECONDS)
- 11 WITHOUT SHEAR
    - 4 FALSE ALARMS

REFERENCE: "AIRBORNE INFRARED WIND SHEAR DETECTOR PERFORMANCE IN RAIN OBSCURATION"; BY PETER KUHN AND P.C. SINCLAIR; AIAA-87-0186; JANUARY 12-15, 1987 RENO, NEVADA.

CONCLUSIONS: RAIN PERFORMANCE

TPS HAS MODELLED AN INFRARED INSTRUMENT IN RAIN

TPS HAS REAL DATA TO VERIFY MODEL

- * FLOWS DATA
- * AIAA PAPER

NUISANCE ALARMS

PROBLEM:

* CRY WOLF SYNDROME

* SAFETY CONSIDERATIONS

INFRARED METHODOLOGY

- INFRARED REMOTELY SENSES TEMPERATURE

- TEMPERATURE DRIVES WINDS

- HORIZONTAL AND VERTICAL WINDS CAN BE INFERRED

- A SUSTAINED DERIVATIVE OF TEMPERATURE ACCOMPANIES A MICROBURST

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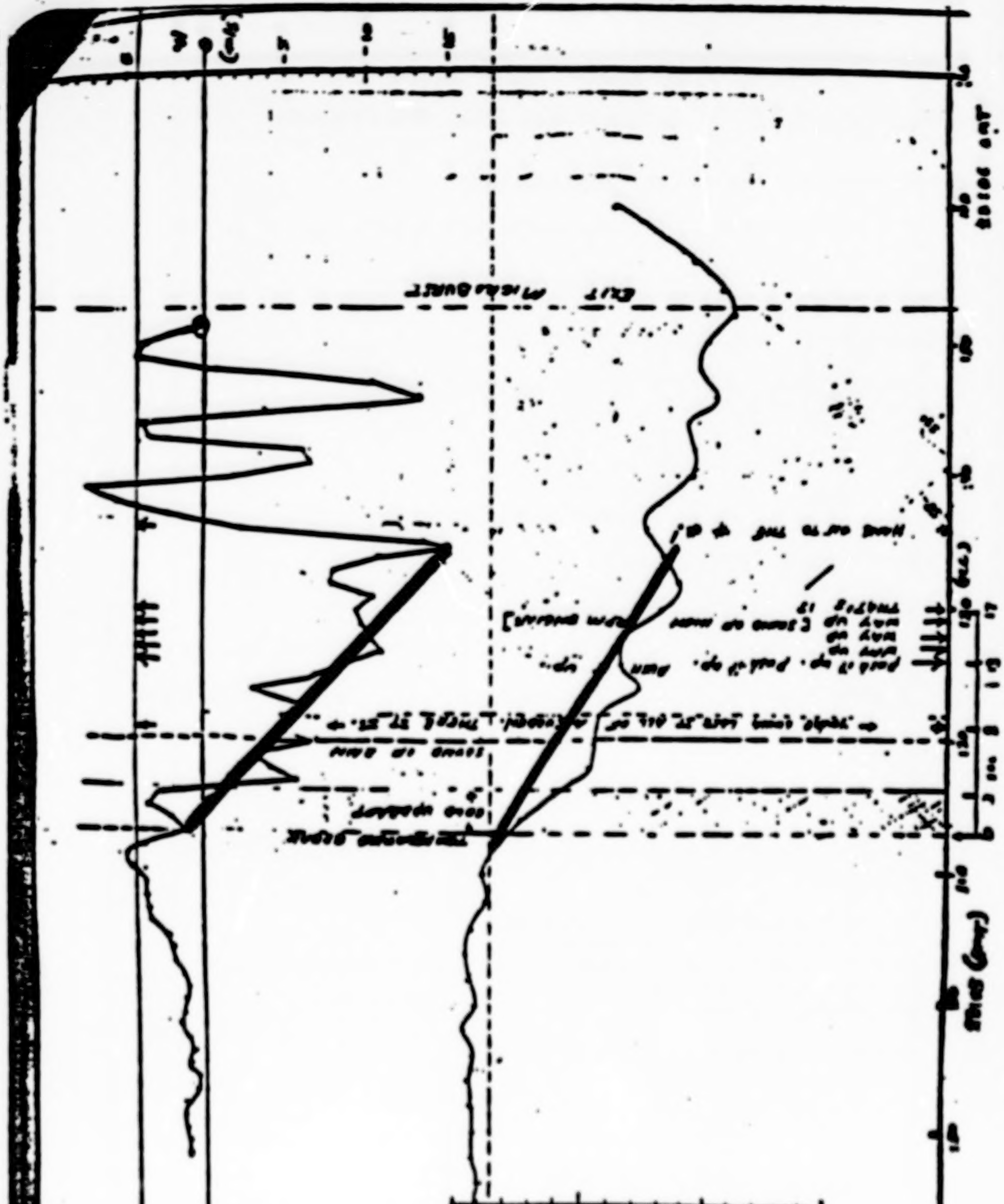

WAYS TO MINIMIZE FALSE ALARMS

* IMPROVE BASIC SENSOR

- TEMPERATURE RESOLUTION 0.05°C

* IMPROVE ALGORITHMS

- HAZARD INDEX (AIRCRAFT SPECIFIC)

* COMPUTER GENERATED EXAMPLES

- EXPLANATION
- DELTA 191 EVENT
- SIMULATED WITH RANDOM 1°C NOISE
- SIMULATED WITH COSINE 1°C NOISE

* IMPROVE COCKPIT DISPLAY

- PROVIDE USEFUL INFORMATION TO FLIGHT CREW

  HORIZONTAL WINDS
  VERTICAL WINDS
  ESTIMATED TIME TO MICROBURST
  HAZARD INDEX
  AURAL CUES

  SEE DEMONSTRATION

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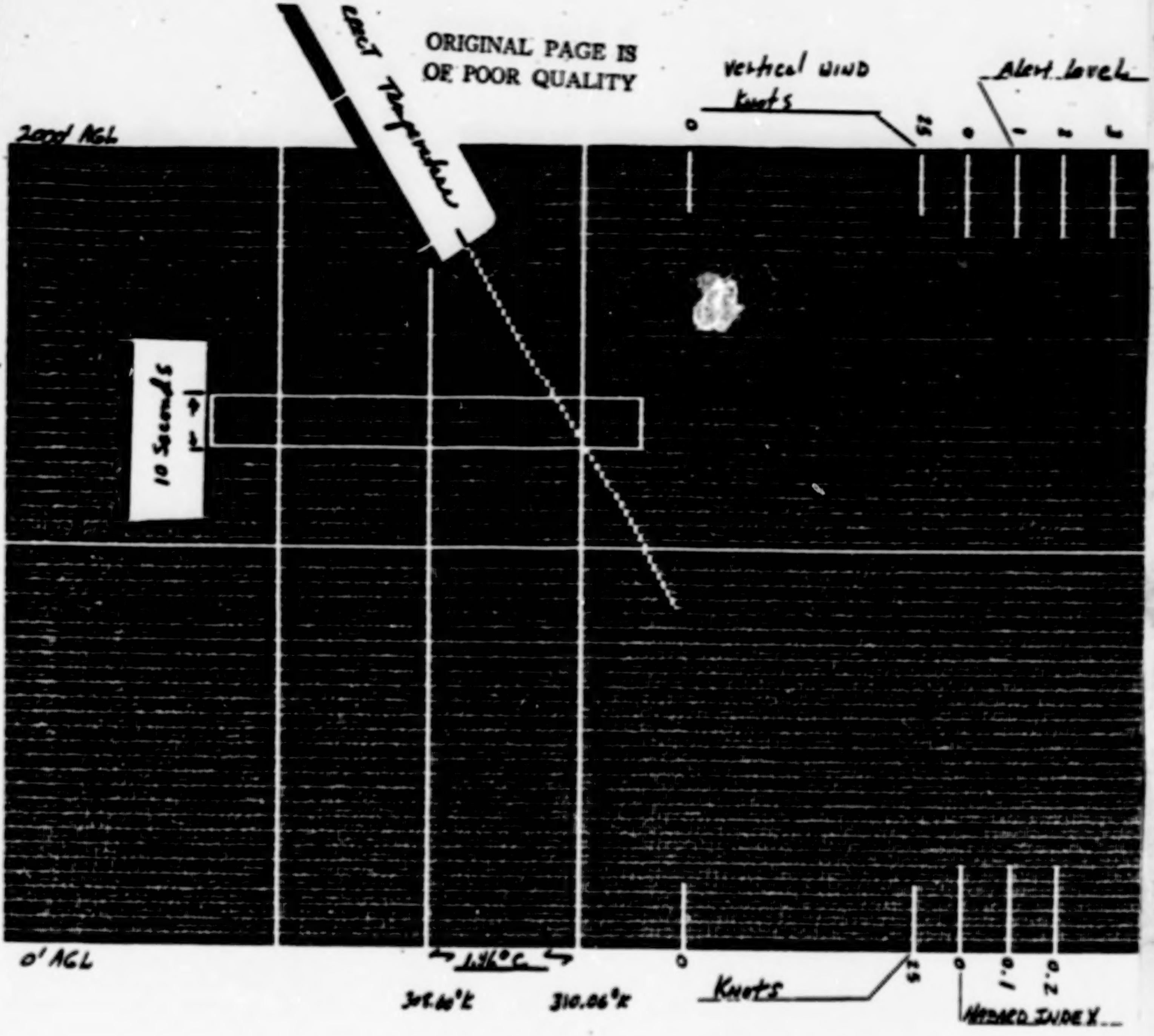


Plane descends @ -12 ft/second

vertical WINDS are downdrafts

10 SECOND box used to get $\Delta T/\Delta t$

HAZARD INDEX is TPS version of $\dot{W}X/g + VN/AS$

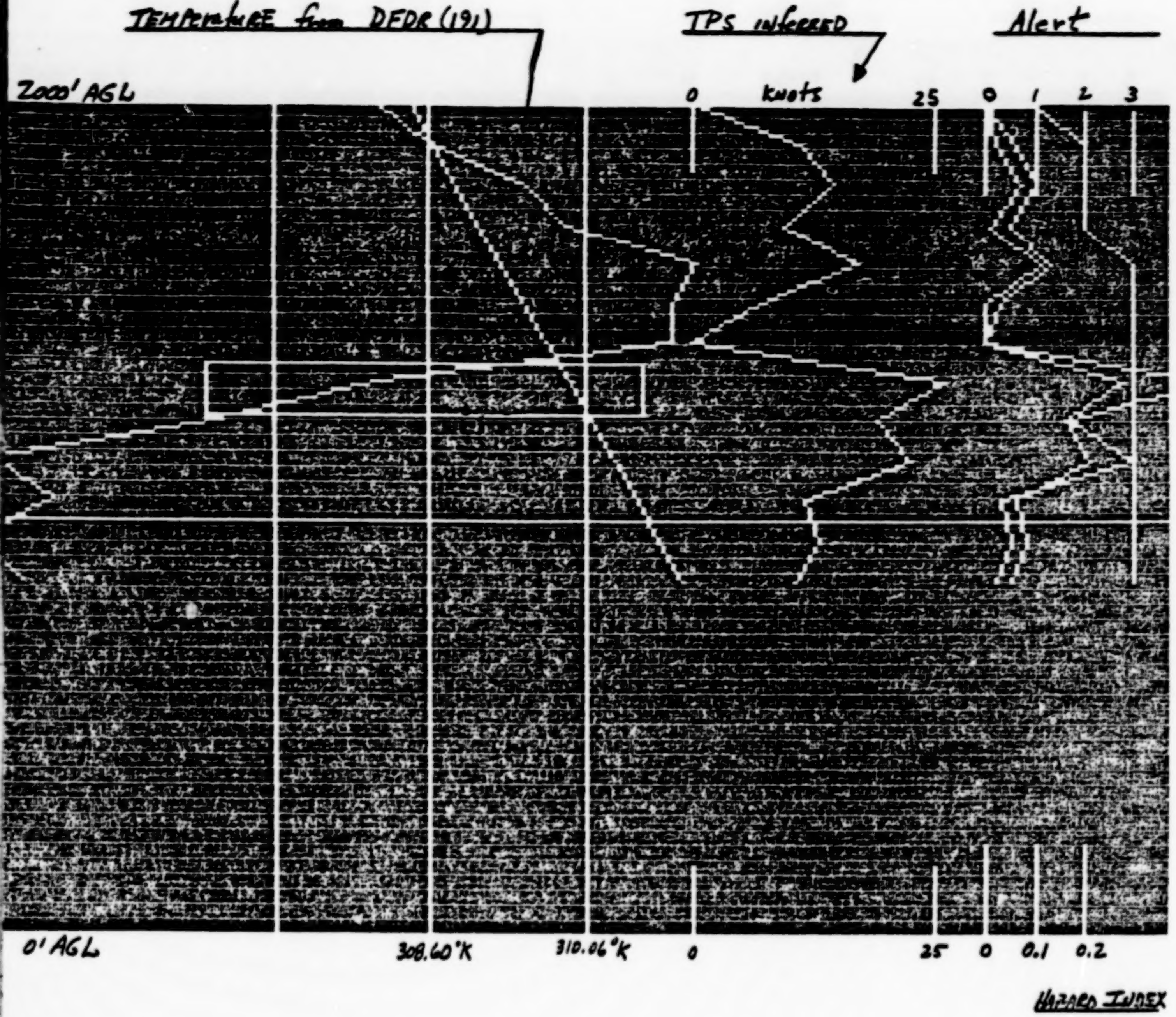
Hazard index is severe >0.2

Alert level by Vertical WINDS 1<10Kts; 2<15Kts; 3>18Kts

TPSWINPB or TPSWINPZ setup

Turbulence Prediction Systems

P.A. 1/6/87



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TPSWINPTS DELTA 191

Turbulence Prediction Systems

P.A. 1/6/87

PB
P2
191
1/2/87

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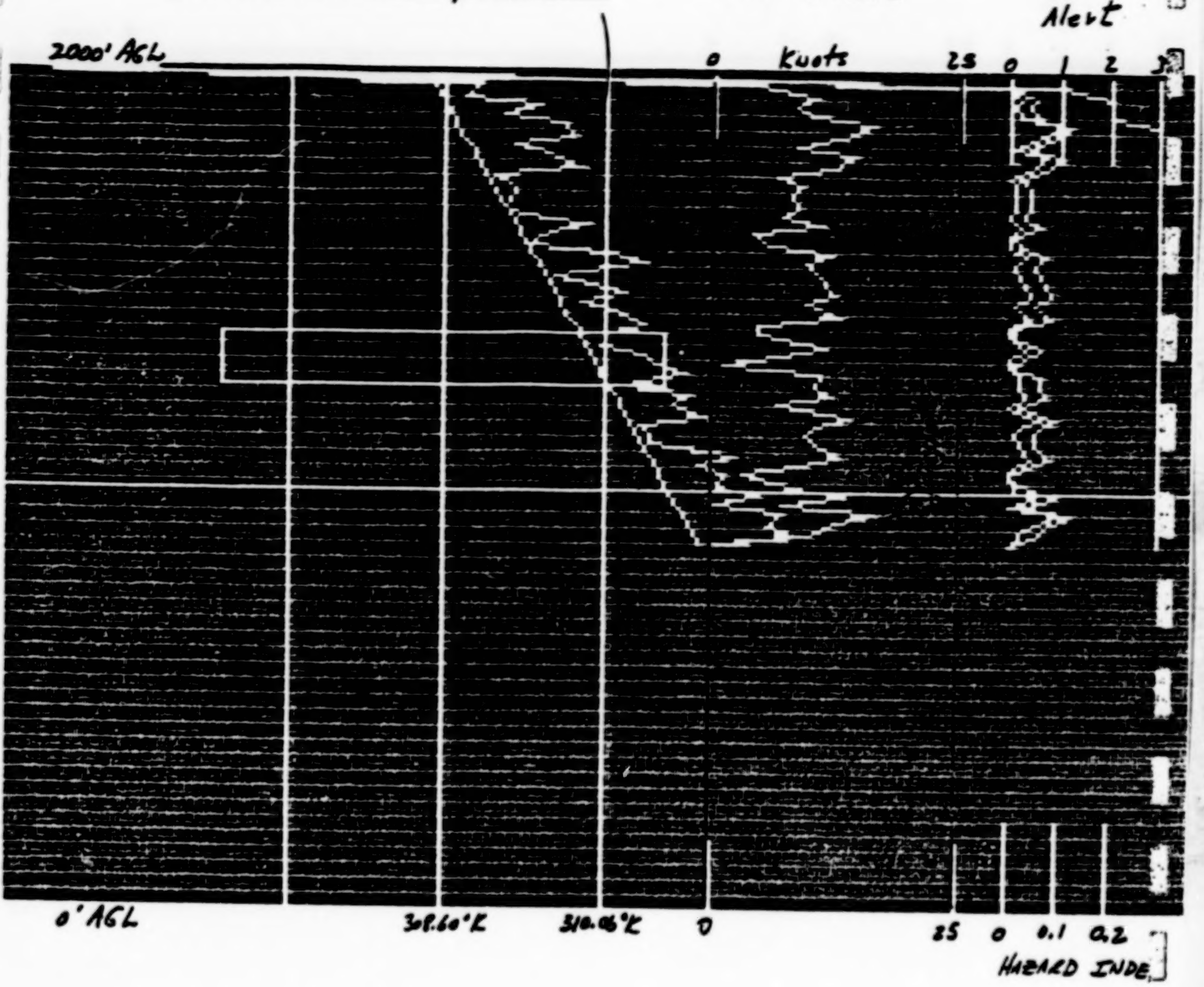
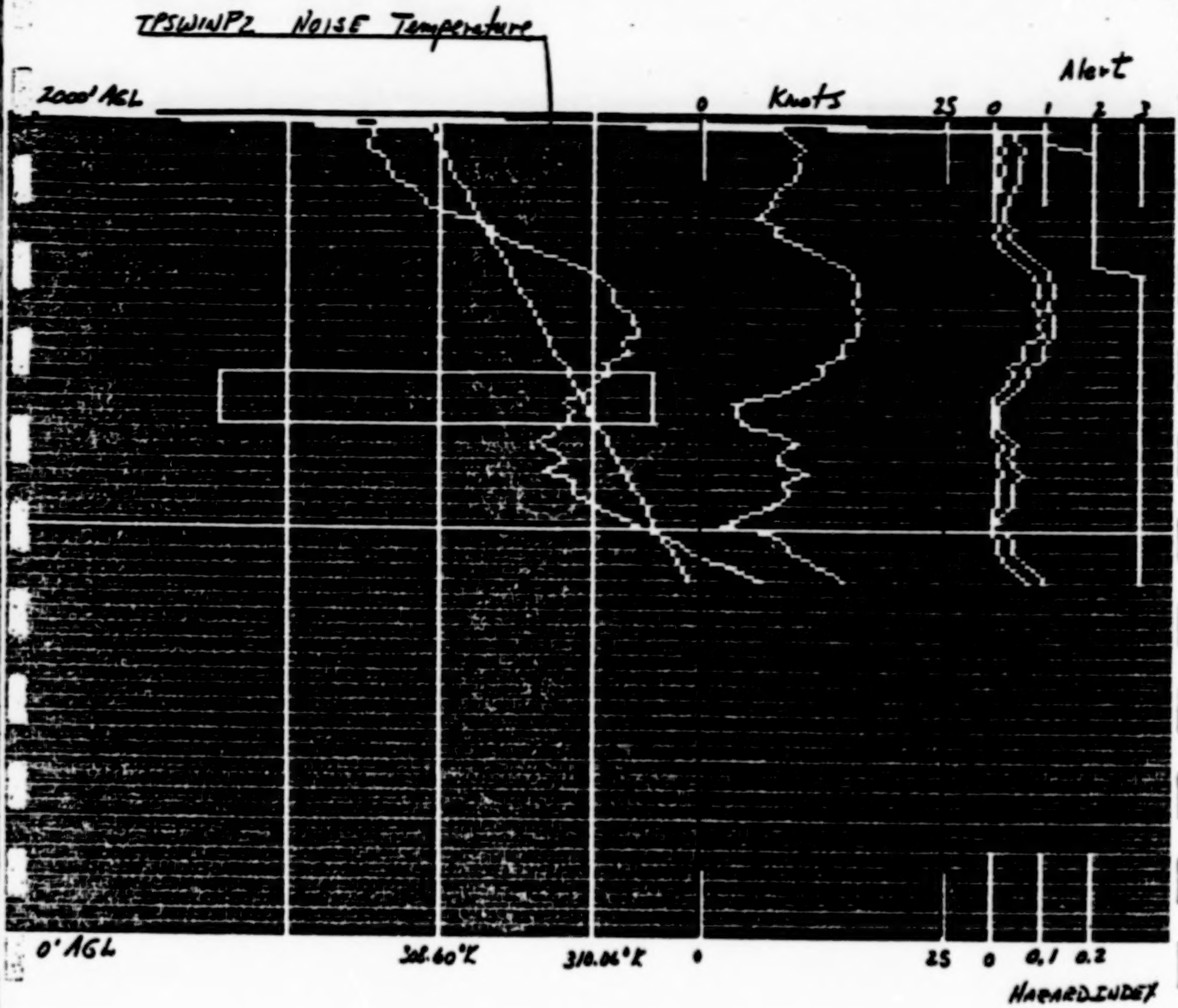
TPSWINPB NOISE Temperature



TPSWINPB Temperature Nois

RANDOM 1°C on temperature

T.P.S. 1/6/87 P.A.



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TPSWINPZ Temperature NOISE

cosine 1°C on temperature

T.P.S 1/6/87 P.A.

P2
[illegible]
1/2/8

PROBLEMS OF PREDICTING DYNAMIC EVENTS

- * MICROBURST 5 MIN LIFE SPAN
- * ADVANCE WARNING 1-2 MIN
  - ○ SOME "FALSE" ALARMS ARE NOT FALSE

- * DYNAMIC EVENTS DIFFICULT TO VERIFY
  - ○ FLY INTO ?
  - ○ DISSIPATED

- * PILOT EDUCATION
  - ○ IDENTIFICATION
  - ○ ACCEPT SOME "FALSE" ALARMS

CONCLUSIONS: NUISANCE ALARMS

TPS HAS IMPROVED THE INFORMATION TO THE FLIGHT CREW

* NEW SENSOR

* NEW ALGORITHMS

* NEW COCKPIT DISPLAY

"AVOIDANCE CAN NOT BE 100%"

PROBLEM:

- EVOLVING MICROBURST
  - NO WARNING
  - REDUCED WARNING TIMES

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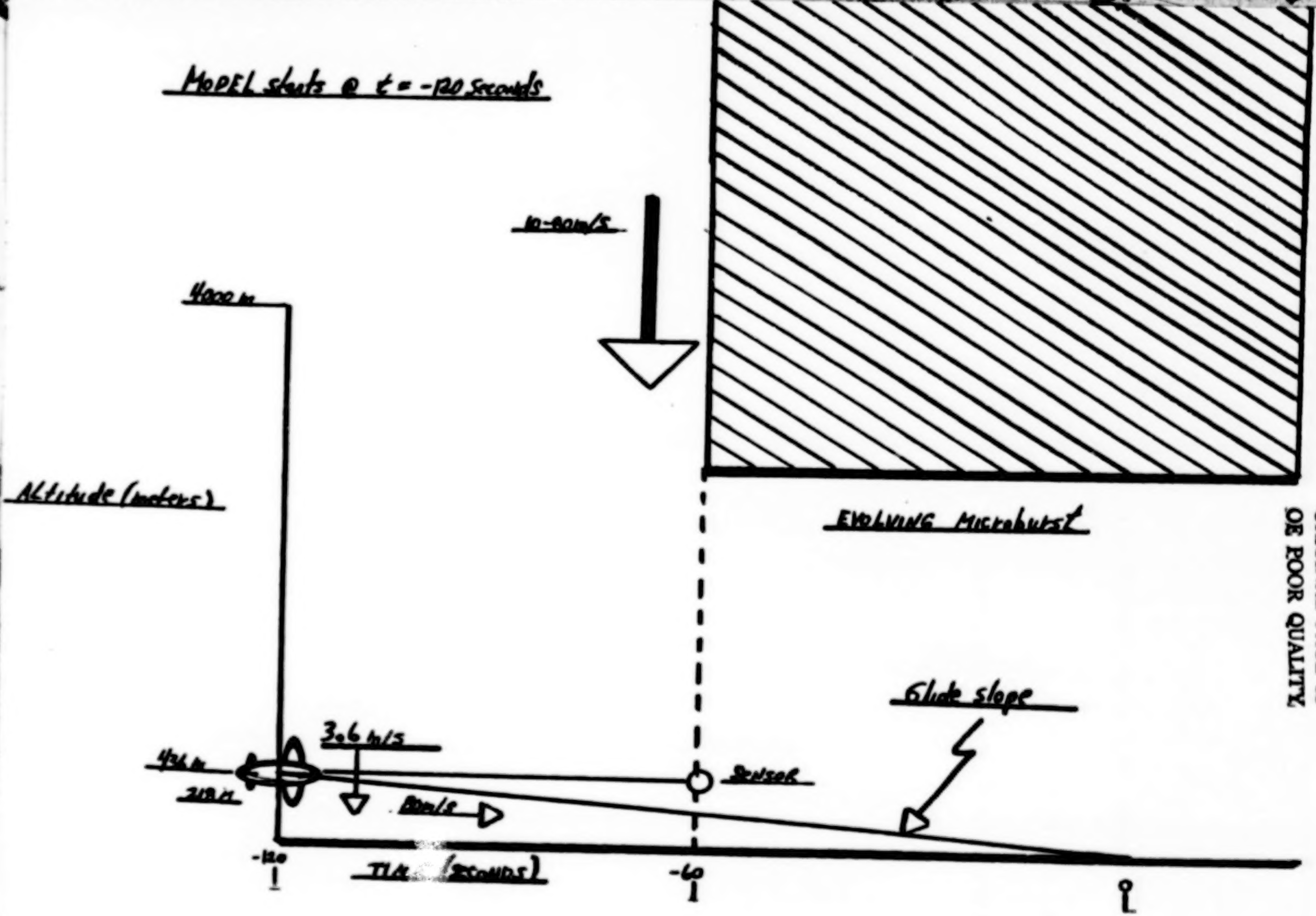


AVOIDANCE Model

POSSIBLE SCENARIOS:

#1- MICROBURST IS LOWER THAN AIRCRAFT

#2- MICROBURST AND AIRCRAFT INTERCEPT AT t= -60 SECONDS

#3- MICROBURST IS HIGHER THAN AIRCRAFT AT t= -60 SECONDS, BUT FALLS ON THE AIRCRAFT BETWEEN t= -60 AND 0 SECONDS

#4- MICROBURST IS HIGHER THAN AIRCRAFT AT t= 0 SECONDS

SCENARIO #1 MICROBURST IS LOWER THAN AIRCRAFT

SYSTEM GIVES ADVANCE WARNING

WARNING TIME = DISTANCE FROM AIRCRAFT TO MICROBURST / (80 METERS/SECOND)

THUS WARNING TIME = -60 SECONDS TO 0 SECONDS

SCENARIO #2 MICROBURST AND AIRCRAFT INTERCEPT AT t= -60 SECONDS

THE ALTITUDE AND THE RATE OF DESCENT OF THE MICROBURST, AT THE START OF THE MODEL ARE SELECTED TO INTERCEPT

RATE OF DESCENT	ALT AT t= -120 SEC
80 M/S	5,018 M
40 M/S	2,618 M
20 M/S	1,418 M

THUS NO ADVANCE WARNING

NOTE: AN INCREASE IN THE LOOK ANGLE WOULD DO LITTLE TO PROVIDE AN ADVANCE WARNING

MICROBURST RATE OF DESCENT IS MUCH GREATER THAN THE AIRCRAFT'S RATE OF DESCENT

SCENARIO #3 MICROBURST IS HIGHER THAN THE AIRCRAFT AT t= -60 SECONDS, BUT FALLS ON THE AIRCRAFT BETWEEN t= -60 AND 0 SECONDS

THE ALTITUDE AND THE RATE OF DESCENT OF THE MICROBURST ARE SELECTED TO INTERCEPT AFTER t= -60 SECONDS

	ALTITUDE AT t=	
RATE OF DESCENT	-60 SEC	-120 SEC
80 M/S	5,018 M	9,600 M
60 M/S	2,618 M	4,800 M
20 M/S	1,418 M	2,400 M

THUS NO ADVANCE WARNING

SCENARIO #4 MICROBURST IS HIGHER THAN AIRCRAFT AT t= 0 SECONDS

RATE OF DESCENT	ALT AT t= -120 SEC
80 M/S	>9,600 M
60 M/S	>4,800 M
20 M/S	>2,400 M

AIRCRAFT IS ON THE GROUND WHEN THE MICROBURST IMPACTS THE AIRCRAFT

CONCLUSION: EVOLVING MICROBURST WARNINGS

1- A CASE CAN BE CONSTRUCTED WHERE THERE IS NO ADVANCE WARNING.

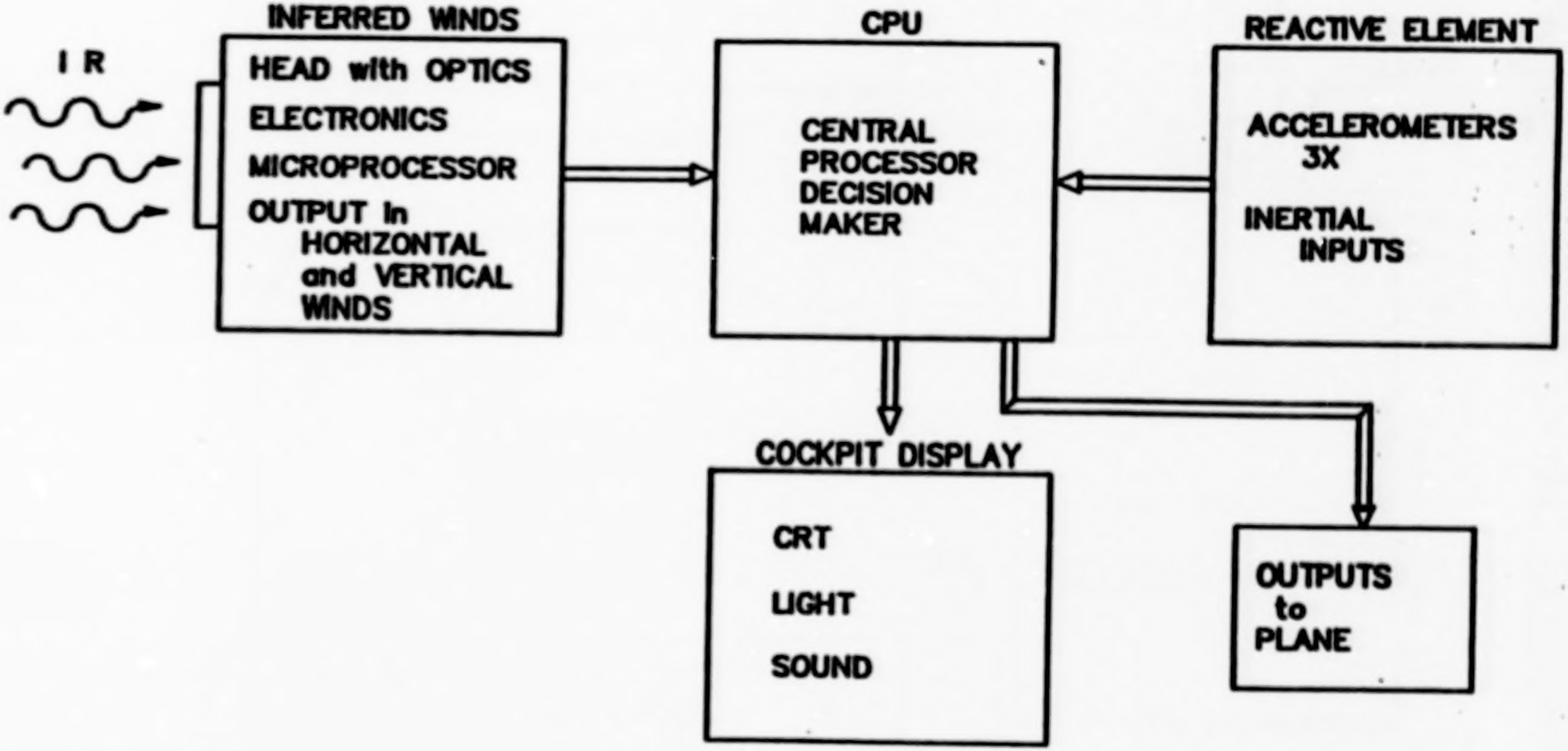
- INCREASED LOOK ANGLE WILL NOT PROVIDE ANY SIGNIFICANT IMPROVEMENT IN ADVANCE WARNING

2- A CASE CAN BE CONSTRUCTED WHERE THERE ARE REDUCED ADVANCE WARNINGS

- INCREASED LOOK ANGLE WILL INCREASE ADVANCE WARNING

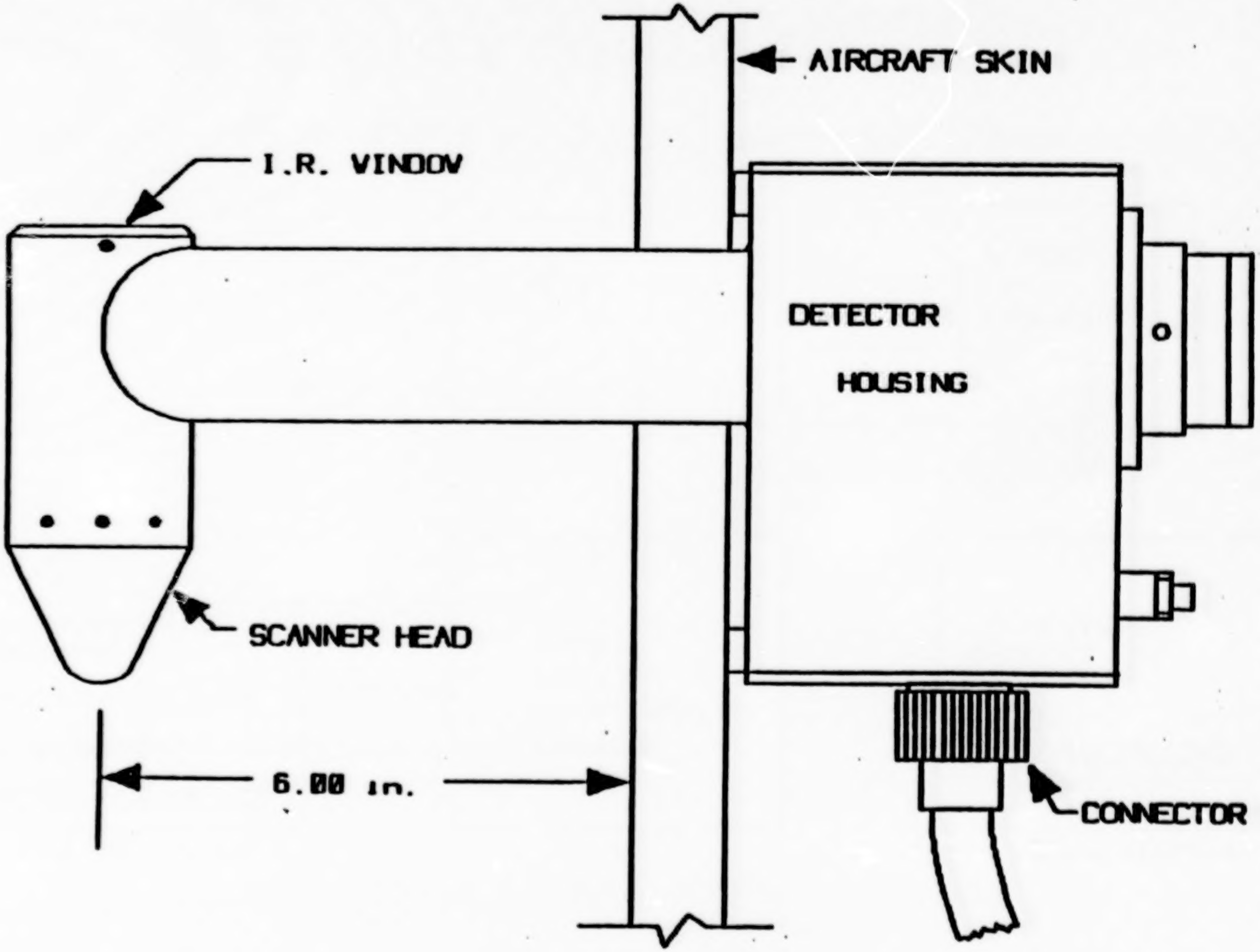
3- INFRARED WORKS WELL WHEN THE EVOLVING MICROBURST IS LOWER THAN THE AIRCRAFT (SCENARIO #1)

4- THUS A REACTIVE BACKUP IS ESSENTIAL



BLOCK DIAGRAM of
TURBULENCE PREDICTION SYSTEMS
ADVANCE WARNING SYSTEM

Turbulence Detector Head



INFRA-RED SYSTEM FOR DETECTION OF WIND SHEAR

W. A. Siarnicki, Delco
T. D. Wise, Hughes

GENERAL CONCLUSIONS

AIR TURBULENCE RESEARCH INSTRUMENT

- EXCELLENT RESULTS
- OVER 1,000 FLIGHT HOURS
- NASA GUST GRADIANT AIRCRAFT USED

AIR TURBULENCE OPERATIONAL SYSTEM

- DUAL PURPOSE (LLWS/CAT)
- NEW GENERATION SENSOR
- MICROPROCESSOR BASED
- COCKPIT DISPLAY

- REACTIVE BACKUP

FAA FORWARD LOOKING DETECTION MEETING

LANGLEY RESEARCH CENTER

FEBRUARY 24, 25 1987

DELCO/HUGHES INTRODUCTORY COMMENTS

QUESTIONS AND CONCERNS

Delco Systems

INTRODUCTORY COMMENTS

- DELCO SYSTEMS - WHO WE ARE, WHAT WE DO.
    1. PART OF GM CORPORATION.
    2. MEMBER OF GM HUGHES ELECTRONICS CORPORATION.
- OUR G&N/AVIONICS BACKGROUND EXPERIENCE.
    1. PERFORMANCE MANAGEMENT SYSTEMS
        AERO DYNAMICS/PERFORMANCE OPTIMIZATION
    2. INERTIAL NAVIGATION SYSTEMS
        TAKEOFF THRUST MONITOR
        WIND SHEAR DETECTION/ANNUNCIATION
    3. RADAR NAVIGATION/TERRAIN AVOIDANCE/AERO PHYSICS STUDIES.

INTRODUCTORY COMMENTS (CONTINUED)

- OUR WIND SHEAR EXPERIENCE - REACTIVE DETECTION.
  1. MECHANIZATIONS
     - 1977 - WIND-ON-NOSE
     - 1978 - VERTICAL AND/OR HORIZONTAL
     - 1984 - CURRENT - COMPOSITE VECTOR SUM
  2. NW ACTIVITIES
     - IN REVENUE SERVICE - 1984
     - AURAL ANNUNCIATOR - 1986
     - CERTIFICATION ACTIVITIES - IN PROCESS

REMOTE SENSING WIND SHEAR

- **BACKGROUND**

  1. **REACTIVE SYSTEMS**

     - **IN-SHEAR WARNING CONSTRAINTS.**
     - **STANDARD SPECIFICATION OF FORM, FIT, FUNCTION - VARIOUS EQUIPMENT IN SERVICE AND STC'd.**
     - **OPERATIONALLY REQUIRES SPECIAL CREW PROCEDURES/TRAINING.**
     - **INSTALLATION REQUIRES EXTENSIVE A/C I/F MODIFICATIONS ON OLDER AIRCRAFT.**

REMOTE SENSING WIND SHEAR (CONTINUED)

2. THE OTHER OPTION – AVOID, AVOID, AVOID THE W/S.

USING AN ONBOARD REMOTE SENSING SYSTEM.

- THIS APPRAOCH HAS SIGNIFICANT ADVANTAGES OVER THE REACTIVE SYSTEM IN THE AREAS IDENTIFIED ABOVE.
- AREAS OF REQUIRED INVESTIGATION LEADING TO DEMONSTRATIONAL FEASIBILITY.
  - TRANSPARANCY OF RAIN.
  - FALSE ALARM SUSCEPTIBILITY/SUPPRESION.

REMOTE SENSING WIND SHEAR (CONTINUED)

- DELCO'S INVOLVEMENT
  - 1985 DSO, AEROPHYSICS DEPARTMENT INVESTIGATING ACTIVE REMOTE SENSING OF THE W/S PHENOMENA.
  - 1986 DSO - HUGHES FORM A W/S SYSTEM R/D TEAM.
  - 1986 PRESENT. DATA ACCUMULATION, INVESTIGATION AND EVALUATION CONTINUES ON BOTH ACTIVE AND PASSIVE FRONTS.

REMOTE SENSING WIND SHEAR (CONTINUED)

- HUGHES INVOLVEMENT

  (TIM HOW ABOUT A SLIDE/S ON YOUR ACTIVITIES.)

REMOTE SENSING WIND SHEAR (CONTINUED)

- CURRENT DEVELOPMENT PLANNING
    - MODELING/SIMULATION ACTIVITIES
    - CONCEPTUAL DEVELOPMENT OF IR & IR HYBRIDS
    - PROTOTYPE DEVELOPMENT
    - FLIGHT TESTING
    - PERFORMANCE OPTIMIZATION

IN PURSUIT OF WIND SHEAR: 1972 - 1987

HUGHES
SANTA BARBARA RESEARCH CENTER
a subsidiary

- DR. KUHN'S WATER-VAPOR RADIOMETER ON BOARD NASA's CV-990 : 1972
- BALL BROTHERS RESEARCH CORP. PROPOSE "CAT" RADIOMETER: 1977
- SANTA BARBARA RESEACH CENTER PROPOSE "CAT" RADIOMETER: 1977 - 1978
- SBRC RENEWS INVOLVEMENT IN WIND SHEAR (LAWS): 1985 - 1987
  - PERSONAL CONSULTATIONS WITH DR. KUHN, DR. CARACENA, & DR. FUJITA
  - GENERATION OF WHITE PAPER ON LAWS NAD WHAT WE PROPOSED TO DO
  - ATTENDANCE AT CONGRESSIONAL HEARINGS WITH DR. KUHN
  - ATTENDANCE AT ANNUAL SESSION OF "MAEITA" AT UNIVERSITY OF TENNESSEE
  - EXTENSIVE IR&D EFFORT AIMED AT MODELING ATMOSPHERIC CONDITIONS
  - CONSULTATION WITH NASA, FAA, ARMY, NAVY AIR FORCE : LETTER CAMPAIGN

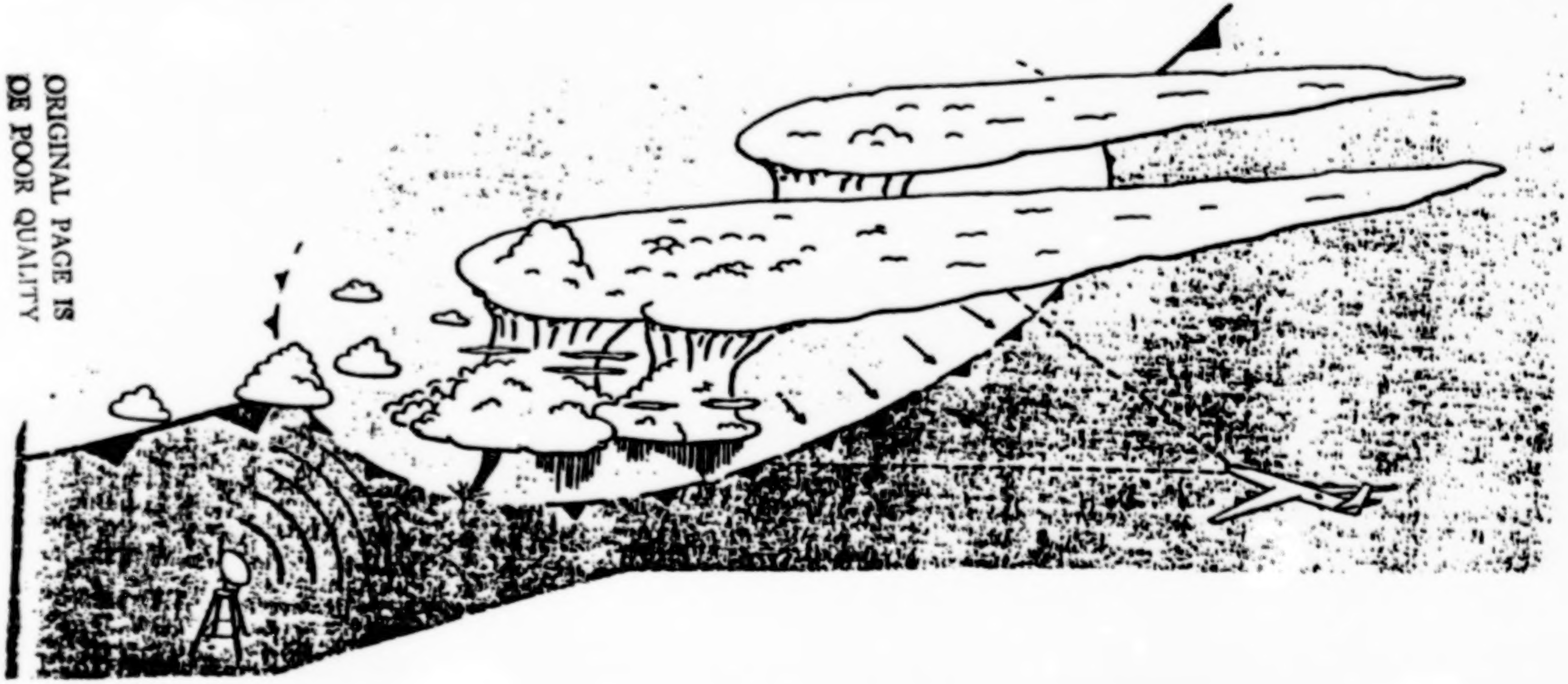
AGENDA: AIRBORNE DETECTION OF WINDSHEAR

- INTRODUCTION
- CHARACTERISTICS, EFFECTS AND AIRBORNE DETECTION OF LOW ALTITUDE WIND SHEAR
- A RECOMMENDED PLAN

LOW ALTITUDE WIND SHEAR (LAWS) CHARACTERISTICS

- EFFECTS
  - INVISIBLE DESTRUCTOR
  - VIOLENT WINDSHIFTS
  - TOROIDAL VORTEX MOTION
  - HIGH VELOCITY DOWN FLOWS PROBABLY LAMINAR
- FORMATION
  - SPAWNED BY COLD AIR MASS GENERATED BY THUNDERSTORM OR VIRGA
  - GUST FRONT IS TYPICALLY 5 - 30 DEGREES BELOW AMBIENT
- DIMENSIONAL CHARACTERISTICS
  - LIFETIME RARELY LONGER THAN 5 - 8 MINUTES
  - HIGHLY MOBILE: MAY MIGRATE 4 - 10 MILES DURING LIFETIME
  - CROSS SECTION MAY BE 200 FEET TO 2 MILES

CONCEPTUAL VIEW OF AIRCRAFT APPROACHING HAZARDOUS WIND SHEAR CONDITIONS



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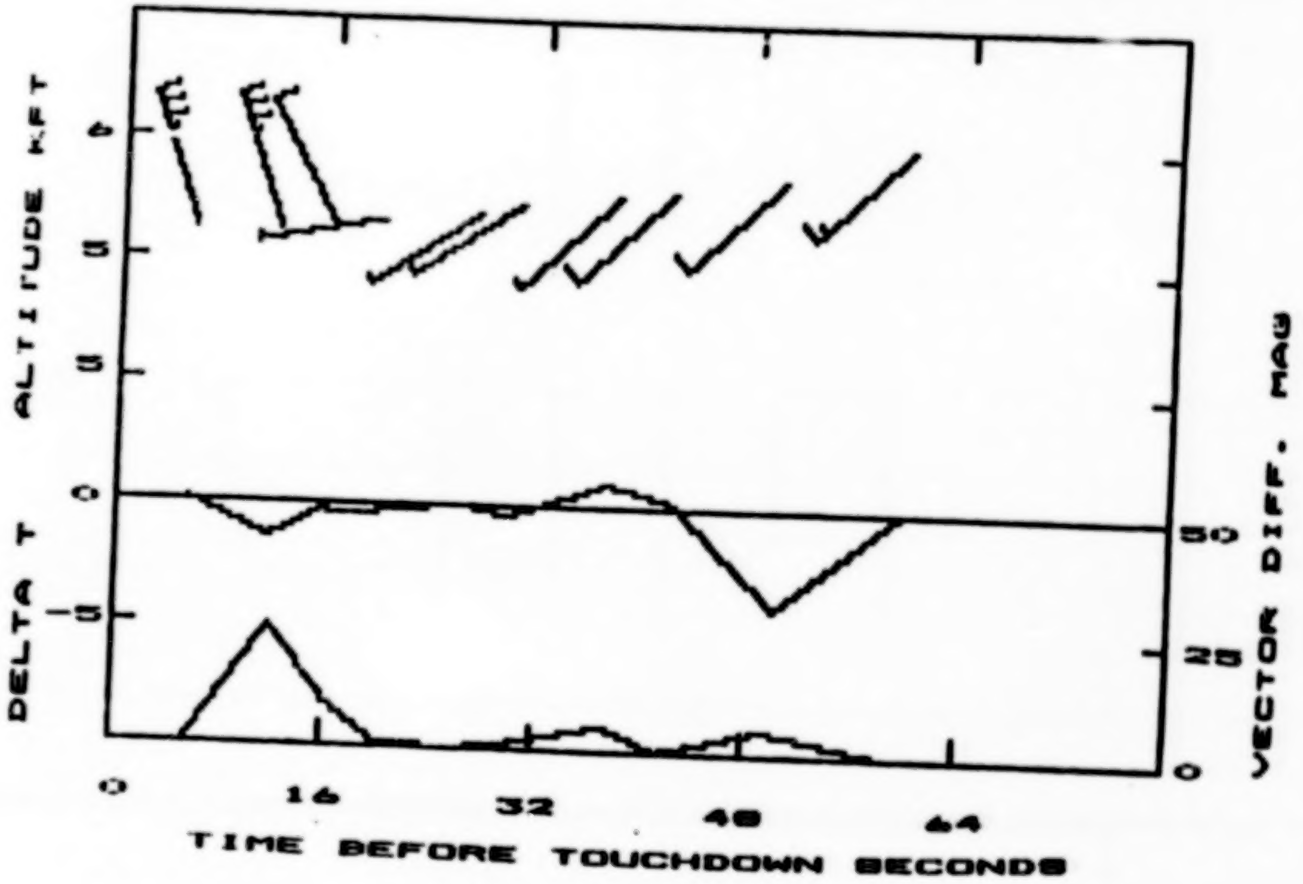
LAWS DETECTION SYSTEMS

- GROUND STATIONS
  - DOPPLER RADAR PER FUJITA
  - PAM
- AIRBORNE SYSTEM TESTED BY DR. KUHN
  - REMOTE TEMPERATURE CHANGE DETECTION

AIRBORNE DETECTION OF LAWS - SHEAR AND TURBULENCE ALERT SYSTEM (SATAS)

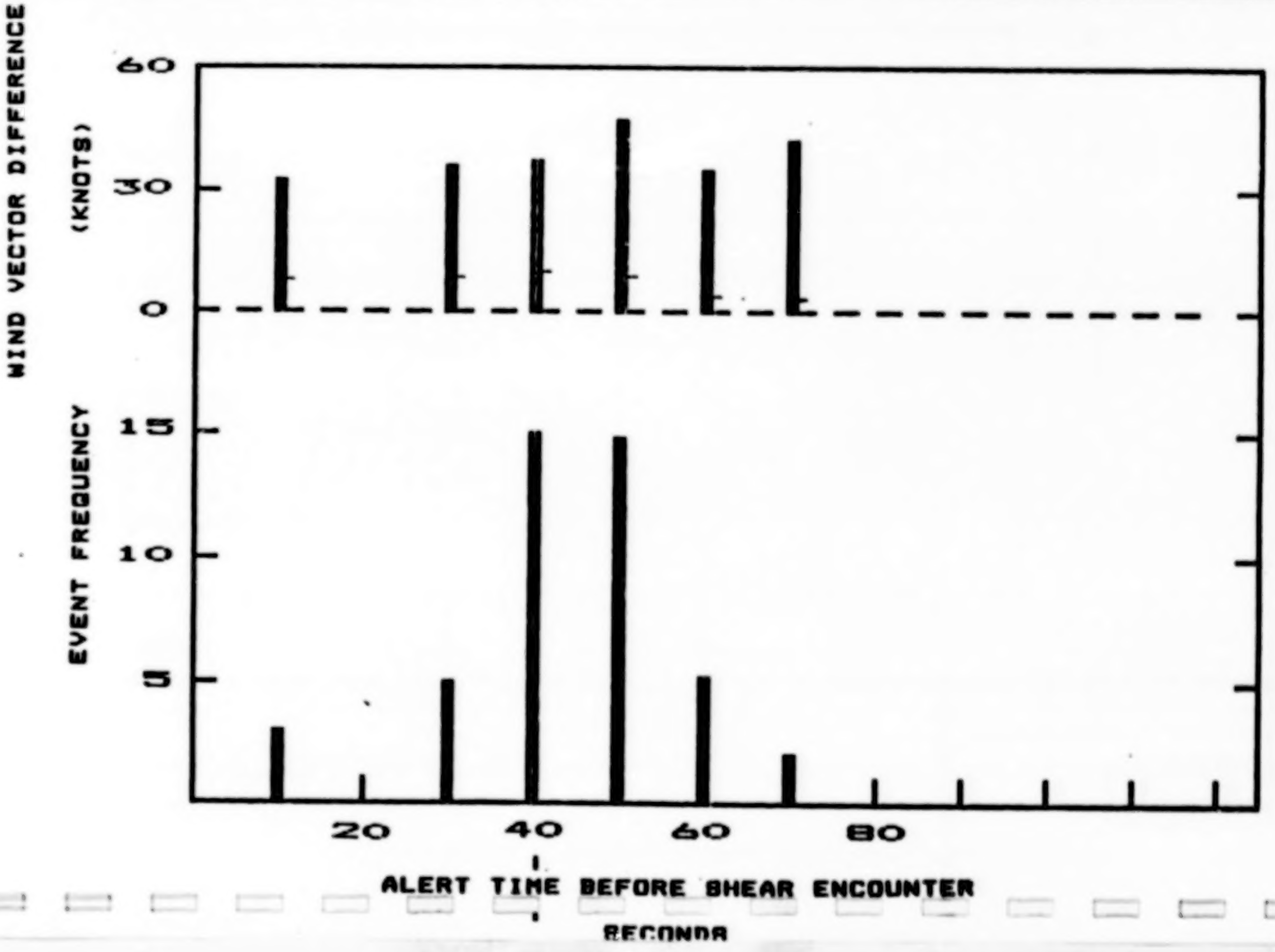
- THE KEY: GUST FRONT 5 - 30 DEGREES COLDER THAN AMBIENT AIR TEMPERATURE
- USE IR RADIOMETER TO SENSE REDUCED CO_2 TEMPERATURE IN GUST FRONT
- DISTINGUISH FROM SIMPLE COLD AIR MASSES BY RATE OF CHANGE IN SENSED CO_2 TEMPERATURE

TYPICAL AIRBORNE ALERT



7/15/82-17

AIRBORNE ALERT STATISTICS - JAWS



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FIELD MEASUREMENTS PROGRAM

- PURPOSE
  - PERFORM DETECTION AND RANGING EXPERIMENTS USING THE H_2O AND CO_2 BANDS AS AN ADJUNCT TO DR. KUHN'S WORK
  - PROVIDE ADDITIONAL ATMOSPHERIC THERMAL STRUCTURE DATA DURING VARIOUS WEATHER CONDITIONS
  - PROVIDE SPATIAL AND SPECTRAL DATA NEEDED TO SUBSTANTIATE ANALYSIS USED IN THE DESIGN OF AN AIRBORNE INSTRUMENT

- METHOD
  - CONSTRUCT AN INTERFEROMETER TO MAXIMIZE SPECTRAL DATA
  - PERFORM FIELD MEASUREMENTS AT A METEROLOGICALLY INSTRUMENTED SITE

- GEOGRAPHIC LOCALES
  - COLORADO; 1000' NOAA TOWER NEAR DENVER; SUMMER
  - FLORIDA; 300' TOWER AT PATRICK AFB; YEAR-ROUND
  - OKLAHOMA; SEVERE WEATHER FACILITIES; SPRING AND FALL

AIRBORNE TEST RADIOMETER

- PURPOSE
  - EXPANSION AND SUBSTANTIATION OF DR. KUHN'S EARLIER AIRBORNE WORK
  - PROVIDE A MOBILE "TEST BED" TO TEST DETECTION CAPABILITY PREDICTED BY THE FIELD MEASUREMENTS PROGRAM
  - SERVE AS A PRECURSOR TO THE PROTOFLIGHTS

- METHOD
  - DESIGN AND FABRICATE AN AIRBORNE ENGINEERING MODEL RADIOMETER WHICH CAN BE MODIFIED AS EXPERIMENTAL EXPERIENCE DICTATES
  - PERFORM FLIGHT TESTS AGAINST TARGETS OF OPPORTUNITY IN THE VICINITY OF METEOROLOGICALLY INSTRUMENTED SITES

- GEOGRAPHIC LOCALES
  - COLORADO; NEAR DENVER STAPLETON; SUMMER
  - FLORIDA; PATRICK AFB; YEAR-ROUND
  - OKLAHOMA; SEVERE WEATHER FACILITIES; SPRING AND FALL

WE RECOMMEND EXPANSION OF DR. KUHN'S WORK

- AIRLINE INDUSTRY INTEREST IS VERY HIGH
- CURRENT PRESSING PROBLEM: QUESTION OF WHEN AND WHERE
- AIRLINE CREW TRAINING NOT SUFFICIENT FOR AVOIDANCE
- PRESENT AIRBORNE ALERT DEVICES PROVIDE NO ADVANCE WARNING
- AIRLINES WANT AN ADVANCE DETECTION SYSTEM ASAP
- FAA ADVISORY CIRCULAR 120-41 HAS DEFINED THE NEED

NOTES ON THE DISCUSSIONS FOLLOWING SEVERAL OF THE PRESENTATIONS

NOTES FROM 24-25 FEB 87 FAA/NASA/INDUSTRY MEETING ON WINDSHEAR

Note: These notes cover only the discussion following each presentation; no notes were made of the formal presentations themselves.

24/0851: (Roland Bowles' discussion on windshear threat & statistics.) Floor discussion about Leo's 1982 flights, LIDAR absorption, radar ground clutter, and IR differential measurements. Peter Hildebrand mentioned dry microbursts. Lead time for escape.

24/0937: (Brac's talk) Floor discussion on spatial resolution in the range direction. Brac answered 200-500 m. Peter H suggested going to a finer resolution, say 100m, and using an RHI display of airborne data. Jim Evans stressed that bugs and birds create false alarms, and so we should use 100m; 250 at the absolute most, since the microbursts themselves can be as small as 500m. His reasoning is that simultaneous returns from several adjacent small cells could more confidently be called a microburst than a return from a single large cell. Leo pointed out that it's OK to go with a single large cell, as long as you can examine its spectrum. Someone said we can't do that just yet, and Peter said we ought to go ahead and figure on being able to do it, because the technology will certainly be there by the time we need it; in other words, don't be afraid to build a more complicated radar. Wally Gillman of American Airlines said that the airlines really need the vertical component of the wind, and Brac explained that present Doppler radar technology just won't do that. Further, Gillman asked for a horizontal sweep of at least +/- 60 deg. Bob Ireland of United Airlines agreed, saying that the pilot wants to know whether to go left or right. Roland Bowles reminded the airline people that the system we're proposing should be viewed as a last ditch effort to save the airplane after all else has failed, not a guidance or navigation system. Jim Evans of MIT Lincoln Labs pointed out that if you do scan +/- 60 deg., then all you need out on the edges is rain cells; wind shear is needed only straight ahead.

Someone wanted to know which was more of a threat to flight: loss of lift due to changing headwind, or forced descent due to downdraft. To answer this, Roland presented his energy balance equations. Roland put forth the question: should windshear limits be set strictly according to meteorological definitions, or should the limits be aircraft-type dependent? (Roland favors the latter.) There followed a discussion between Roland and Jim Evans on detectable wind speed differences and the minimum distances over which they occur. Roland noted that even short-term turbulence affects lift, by messing up the laminar flow over the wing.

Someone wanted to know the power level of the SAR, and Bob Onstott of ERIM responded "several kW." J. J. Ewing of Spectra Technology wanted to know if the wind speed correlates well with the rain motion, to which Leo replied in the affirmative.

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Brac presented Jim Schrader's airport diagram, and there followed a floor discussion of the gray levels. Les Britt reminded the folks that the absolute numbers should be ignored for the time being; at present we're just trying to develop the model. Brac pointed out that we're not trying to build a subtractive map; but rather we're trying to understand the statistics so we can develop a process to suppress clutter. Jim Evans wanted to know how the RTI/AMRB model gets the velocities, and what it is that we're seeing. Les responded that these are bins of range vs. velocity shift, taken from the line spectrum, and it is radial component only, and that the range bin resolution in range is 150 m. Jim Evans stated that the Huntsville experimental data does not support the 8 to 10 m/sec spectral width shown in Britt's plot; 1 m/sec would be more like it. Jim brought up lots more questions about signal processing, to which Les replied that we really haven't tried any processing yet, except to compute a simple FFT.

It was pointed out that the broad spectrum, shown in the spectrum plot presented by Britt, was due primarily to the large spatial volume (425mx150m), seen by a 2.7 deg beamwidth antenna and 1 microsec pulse at a 9km range looking at a vortex area of the wind field. The wind speed and directions in this particular resolution volume varied over a wide range. Subsequent spectrums at other portions of the wind field, even for this large volume, showed spectrum widths on the order of 4-5m/s. At shorter ranges, where the spatial volume is smaller, the spectrum width is smaller when looking at more constant wind field conditions. The 1 m/s spectrum widths seen by the Lincoln Lab. radar correspond to much smaller resolution volumes (0.7 deg beamwidth; 109 m resolution at 9km). The question of velocity spectrum width that exists in microburst windfields as seen by Doppler radars must be studied further.

At this point, someone pointed out that using meters per second and kilometers makes it very confusing to translate our results and specifications into useful cockpit numbers. All instruments in U. S. transport aircraft are in knots and feet, and we should realize that that's where our end product will be used.

24/1315 (Peter Hildebrand's talk on NCAR's radar) Wally Gillman of American Airlines disputed Peter's observation that pilots generally turn off the radar on approach; Wally maintains that they really just switch modes. Also, Wally says that in the specification of the windshear-seeking radar, we are confusing minimum requirements with the target design. As an example, he'd like to see the windshear warning occur 10 miles ahead (target design), but that 5 miles would be the minimum requirement.

24/1345 Wally Gilman (American Airlines) presented some thoughts from a pilot's viewpoint on providing microburst hazard warning to the pilot. Must re-think the attitude on the use of weather radars for providing information on weather hazards to the pilot. Will it remain just an advisory sensor which pilots use as they see fit or will it be a certified hazard warning device required on all a/c? Thinks future radars should have multi-modes of operation from providing reflectivity and turbulence information when away from the airport to microburst hazard detection during landing and take-off. Mode switching would be automatic in which range, scan angles, processing and display

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information, etc., would change as the a/c comes in to land. Suitable displayed information, easily interpreted by the pilot, must be provided. Thinks 30-40 sec. warning is too short a time to allow for escape. Should provide hazard information much further out during the landing phase. R. Bowles pointed out that the 30-40 sec. warning is a minimum requirement and does not imply that warning information at further distance from the a/c will not be provided.

24/1400 R. Robertson and D. Alitz (Rockwell-Collins) presented brief review of their activity in development of radars for windshear detection. Need good simulation data to evaluate system designs. Difficult and expensive to collect real world data under all conditions. Need good models and statistics of the microburst characteristics. Thinks that good simulation schemes will be the major source of certifying any forward sensor design. Field testing for verification is too expensive and time consuming, due to the relative rarity of the hazard being sensed. Field tests should be used to verify the accuracy of the simulation.

Russell Targ (Lockheed) presented a review of a strawman CO_2 Lidar system design along with some performance trade-off information. Since rain rates are the chief obstacle to acceptable Lidar operation, the rain levels encountered by or existing in front of a/c during a potential microburst encounter must be quantified. The problem of rain or layers of water on the Lidar lens must be addressed, since water on the lens may severely reduce the Lidar's range of operation. The Lidar strawman design proposes using a 15 deg conical scan of the laser beam in order to obtain the x,y,z components of the wind vector. It was pointed out by C. Fricke that this technique only works for a constant wind field within the conical scan volume. Since the microburst hazard has significantly varying wind velocities and direction within small volumes of space, significant errors in the wind direction components would occur. Reducing the conical scan angle to look at smaller volume would significantly reduce the geometric accuracy of the three vector components. This technique as well as others must be further studied to see if other then the radial component of wind speed in the outflow area can be measured.

H. Schlickenmaier (FAA) proposed two key questions that he feels the group needs to address and answer. They are:

(1). WHAT IS THE HAZARD BEING SENSED? List which of the characteristics of the microburst hazard must be sensed, describe how the a/c reacts to the hazard, and define how the information is to be provided to the pilot.

(2). HOW DO YOU TEST THE SENSORS DEVELOPED AGAINST THE DEFINED HAZARD?

24/1600 (Frank Allario, Chief, Flight Instrumentation Div.) Made comments on the state-of-the-art in solid state laser technology. Presented review of NASA's ongoing basic R & T work in that field. Discussed future space-based laser/lidar systems being developed for the space station and Earth observing polar orbiting spacecraft. Feels that CO_2 laser technology is here and could be used in the design of a windshear detection lidar. Solid state lasers for this application, especially in the eye-safe region above 2 microns wavelength, will require much further development before reliable production crystals can be obtained. Feels confident that solid state lasers for lidars will be available a number of years down the road.

25/0830 (Spectra Tech's presentation on Lidars) Bottom line for this talk was that laser technology can provide a windshear detecting system, except for size and expense. A question about EMI brought the answer that the generation of a short pulse necessitates shielding to protect other equipment. Roland wanted to know if there is any support to breadboard up a system. Answer: no one is clear on where to get the support. Leo wanted to know about frequency stability, noting that the present instability translates to an uncertainty of 1 m/sec. Spectra Tech's reply was that averaging successive pulses can reduce this uncertainty.

25/0848 (Milt Huffaker, Coherent Technologies. Discussion of Doppler Lidar) Roland wanted to know if the lidar beam can be tilted down (yes), and if there is data for near-grazing (yes). And if at Huntsville the lidar could see stuff that Evans' setup couldn't (also yes). Peter Hildebrand pointed out that this difference could have been due to siting problems. Someone wanted to know what software was used. The answer was that a program from the Air Force Geophysics Lab is being used, and they're trying to get aerosol species as well as the winds. Then some questions about penetration of turbulence, the turbulence and the aerosols both being most prevalent near the ground. Bob Hess suggested going to longer pulse Doppler. Huffaker replied that they're now already using 2 to 3 microsec. Someone wanted to know what limits the range of the lidar, and the answer was that a pulsed CW system is power limited, and that for a focused CW system the depth of field increases with increasing range. (This means that the ability to resolve range deteriorates.) At 1 km range, the depth of field is about 1 km.

25/0948 (Pat Adamson, of Turbulence Prediction Systems, on IR) Someone asked what level of temperature contrast constitutes an alert. The answer was -0.5 deg/sec, observed for at least 8 sec. The beamwidth? 2 deg. Method of ranging? A spectral method, using weighting functions, detuning from center frequency, and comparing absorptions at two different wavelengths. Peter Hildebrand asked about temperature contrasts in rainshafts that don't produce microbursts. The reply was that the atmosphere model needs expansion, and the algorithm needs improvement. Then some lively discussion on "wet" vs "dry" microbursts. Roland wanted to know why the IR model is predicated on du/dz rather than du/dx. The answer was that if du/dz is good enough for Peter Kuhn, then it's good enough for you, to which Roland expressed his displeasure. A question about ranging brought the answer that range gating in an IR system is less of a problem than for lidar (note: how do you range gate a passive system??) Roland mentioned that for several years now, Northwest Airlines has specified a go-around if a temperature contrast of at least 12 deg is detected in the presence of winds of at least 15 knots. Roy Robertson of Collins asked how the system degrades in heavy rain. The answer was that there is a graceful degradation, with the usable range gradually decreasing. Can you look down the

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glideslope? Yes; the hot earth will register as a constant, with not enough contrast to sustain the required -0.5 deg/sec over 8 sec. However, the presence of the hot earth would mask the ability to detect small temperature changes. It was recommended that the IR sensor be used in an up-looking operation to avoid seeing the warm Earth, in order to detect the down flow region of a microburst where a significant temperature gradient can be detected. Roy wanted to know what the biggest hurdle is for IR. Milt replied heavy rain. It was pointed out that heavy rain on the IR sensor window would make the sensor incoperative. What about angular FOV? +/- 20 deg, which crabs with the airplane.

25/1118 (Wayne Siarnicki of Delco and Tim Wise of Hughes, describing another IR system, using a modified Barnes PRT-5) Roland asked when there will be an ARINC-compatible system. Answer: 18 to 24 months, maybe a scientific field instrument in the summer of 88. It will stare, and then scan at a later time. And it will cover several CO_2 bands. No improvements in range over the previously described system were claimed. Roland asked if Hughes and Delco are committed to proceed on this project regardless of outside support. Answer: Yes to study the feasibility; no to build a complete system.

KEY ISSUES-
UNRESOLVED QUESTIONS
TO ADDRESS AT
FUTURE MEETINGS

The following questions were formulated by Delco before the meeting got underway, then were furnished to NASA after the meeting's conclusion.

QUESTIONS/CONCERNS

1. WHAT IS THE NASA AND FAA POSITION ON THE FEASIBILITY, PRACTICALITY AND ACCEPTANCE OF THE VARIOUS FORWARD-LOOKING DETECTION TECHNIQUES? IN OTHER WORDS HOW WOULD YOU RATE THE SUCCESS FACTOR FOR THE VARIOUS APPROACHES?

2. WHAT TIME FRAMES ARE WE LOOKING AT AS REGARDS TO THE AVAILABILITY OF THE VARIOUS FORWARD-LOOKING WIND SHEAR DETECTION SYSTEMS?

3. DO NASA AND/OR THE FAA PLAN TO FUND EVALUATIONS OF ANY OR ALL OF THE FORWARD-LOOKING DEVICES OR TECHNIQUES?

4. DOES THE HAZARD DEFINITION FOR REACTIVE SYSTEMS ALSO APPLY TO FORWARD-LOOKING WIND SHEAR DETECTION SYSTEMS?

5. WHAT SHOULD BE THE DESIGN GOALS OR CRITERIA FOR LLWS DETECTION (RANGE AND SHEAR CONDITION) AND PROBABILITY OF SUCCESS FOR AN ACCEPTABLE SYSTEM? WHAT CONDITIONS ARE OF GREATEST CONCERN IN VIEW OF EXISTING AIRBORNE AND TERMINAL AREA SURVEILLANCE CAPABILITIES AND CURRENT PROCEDURES? (I.e., PILOTS DO NOT FLY, OR ARE NOT DIRECTED INTO HEAVY THUNDERSTORMS).

6. IN VIEW OF THE TRADE-OFFS BETWEEN SENSITIVITY, DETECTION THRESHOLDS, DISCRIMINATION TECHNIQUES AND COMPLEXITY OF THE SYSTEM, WHAT FALSE ALARM RATE WOULD BE ACCEPTABLE FOR SUCH A SYSTEM IN THE APPROACH AND TAKEOFF ENVIRONMENT?

7. SHOULD A GUIDANCE/RECOVERY METHOD BE A REQUIREMENT OF FORWARD-LOOKING WIND SHEAR DETECTION SYSTEMS?

8. WHAT DOES FAA ENVISION AS GENERAL CERTIFICATION REQUIREMENTS FOR FORWARD-LOOKING SYSTEMS? WILL THERE BE APPLICATION OF EXISTING WIND SHEAR AC'S AND RULES? IS THERE A PLAN FOR DEVELOPING THESE REQUIREMENTS?

Delco Systems

ISSUES GENERATED AT THE MEETING

The following list of key issues was generated at an informal meeting which started at noon Wednesday, following completion of the formal presentations.

1. Needs and education of the users/operators: How do I use the system? What can the system do, and what are its limitations? Also, we don't want the airlines interpreting this effort as a coalition between government and the manufacturers to sell them yet another black box.

2. The previous day's comment about m/sec and km not being cockpit units was repeated. By continuing to use these otherwise acceptable units, we are isolating ourselves from our end-product users.

3. Among all the options for forward-looking sensors, what outputs are common to all the sensors (i.e., independent of choice of IR, Lidar, or radar)? Are we ready to come up with a strawman list of these outputs so that we can tell the potential user what parameters he can expect to have available?

4. Define scanning schemes, fields of view, range, parameters to be sensed, and the accuracy of each. Need to define each of these, both in terms of what technology might provide and what the user will require. Which are the wind components to be sensed: horizontal or vertical?

5. Will the system to be developed be used as a continuous advisory over 5 to 10 minute intervals, or is it to be a last-second warning for avoidance?

6. Should we think in terms of warning lead times, or warning lead distances?

7. Certification of the system: Should the operating limits on the system be airplane-specific or should they be meteorologically defined? What about false alarm rates? And the relationship between ground-based and airborne-derived warnings?

8. We must define the hazard and find out where the threat exists. Below 1000 ft and inside the outer marker?

9. How close can simulation models of the microburst hazard match the real world when anomalous data as seen in field measurements, are not incorporated into the model? How do you model these phenomena, and how significant are they?

10. What is the best way to resolve the differences seen between the simulations of the hazard and the field data? How do you resolve the differences in the Doppler spectrum widths shown in the simulation with those seen in ground Doppler radar?

25/pm (Smaller meeting with Bowles, Evans, Staton, Huffaker, Britt, Schrader, Bracalente, and Delnore) Lots of discussion to try to discover why the field of calculated wind speed differences is apparently not supported by the Huntsville data. Also some discussion of triple Doppler offering no advantage (at low altitudes) over dual Doppler. These topics will be part of a continuing dialogue among the researchers involved, and certain aspects of the sharing of data were discussed but not resolved.

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16. Abstract

A meeting was held at the NASA Langley Research Center in February 1987 to discuss the development and eventual use of forward-looking remote sensors for the detection and avoidance of wind shear by aircraft. The participants represented industry, academia, and government. The meeting was structured to first provide a review of the current FAA and NASA wind shear programs, then to define what really happens to the airplane, and finally to give technology updates on the various types of forward-looking sensors. This document is intended to informally record the essence of the technology updates (represented here through unedited duplication of the vugraphs), and the floor discussion following each presentation. Also given are the key issues which remain unresolved from the meeting.

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